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THE INFLUENCE OF GEOGRAPHIC CONDITIONS UPON ANCIENT MEDITERRANEAN STOCK-RAISING*

ELLEN CHURCHILL SEMPLE

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GEOGRAPHIC DETERRENTS TO PASTORAL NOMADISM.—" It is weather rather than soil that determines the harvest " in Mediterranean lands, said the Greek Theophrastus. It was climate which determined the pasturage there, causing its mediocre quality, its limited quantity and its seasonal distribution through the year. The poor endowment of this region with good grazing revolutionized the economic life of all those pastoral tribes who pushed into the Mediterranean Basin, from the well-watered Danube valley on the north and the vast undulating grasslands on the east. Here Nature offered for their occupancy only limited areas, whose boundaries were drawn by the " unpastured seas," to use Homer's expression. Here steep mountain barriers discouraged nomadizing, while the low valleys and narrow coastal plains provided fodder only half the year. Therefore from the arrival of the Israelites and other Semitic hordes in Palestine to that of the shadowy Pelasgians in Greece and Italy, these conditions forced a more or less rapid decrease in the flocks and herds of the pastoral invaders, and hastened the

* Presidential address before the Association of American Geographers, Washington Meeting, Washington, 1921.

advance from nomadism to sedentary agriculture. The Jewish Scriptures, the Iliad and Odyssey, the traditions, customs and religious institutions of primitive Latins, Celts and Iberians, all point to a former preponderance of stock-raising gradually superseded by tillage. Grazing survived, but hardly as an adjunct of tillage. It evolved along lines alien to the rainy lands of the north and to the semi-arid lands to the east. It developed the semi-nomadic summer shift to the highland pastures, familiar in the Swiss Alps and the Scandinavian mountains, but arising from quite different geographic causes, and attended by quite different economic results.

Stock-raising in the ancient Mediterranean world bore the unmistakable impress of its environment. It was conditioned primarily by the summer drought. This destroyed pasturage in the lowlands for two to six months, according to the latitude, and permitted the shallow-rooted herbage to survive only on swampy coastal belts, deltaic flats and mountain-locked lake basins in which the ground-water table was high. Such choice but limited spots furnished the wet meadows or marsh pastures, which the ancients reserved for their brood mares, horses and fine cattle, and which they sometimes guaranteed against failure in exceptionally dry seasons by artificial irrigation. Yet even these grassy areas shrank to mere patches of green as the summer advanced, unless the streams which watered them flowed down from high mountains with lingering hoods of snow.

Effect of Relief Upon Mediterranean Pasturage.—The Mediterranean lands made some compensation for the summer drought by their prevailing mountain relief, which provided summer pastures on the heights. The great altitude of the young folded ranges and massive horsts which almost surround the Mediterranean and its Black Sea alcove, their extensive distribution from the Rif Atlas to the densely wooded Caucasus, and their immediate proximity to the vapor-yielding seas, all combined to sprinkle the Mediterranean lands with lofty climatic islands of persistent verdure, wherever the slopes rose high enough to take a toll of moisture from the passing clouds. Here the lowly herbage of the sod flourished the summer through, screened from the sun by the deciduous forests of the upper slopes, nourished by the bed of moist humus about their roots. The summer pastures of the Mediterranean highlands, however, did not offer the variety of grasses and nutritious herbs found in the Alpine meadows farther north; nor did they wear so long the covering of snow which subjects the soil to a slow process of saturation and promotes growth through the ensuing months of sunny days. Therefore, except on the high Alpine rim of the Mediterranean Basin, the flocks and herds grazing

on the mountain pastures have always had to eke out their grass diet by the fresh shoots and accessible twigs of the deciduous trees. This supplementary fodder was undoubtedly more abundant and varied in ancient times than now, when the forests are the thin and deteriorated residue left by centuries of denudation. Moreover, the original forest covering conserved the moisture in the soil of the slopes, and thereby maintained a richer pasturage of herbs and grasses than exists there today.

The quality of the mountain pastures declined from north to south and from west to east within the long flattened ellipse of the Mediterranean lands, and it fell off rapidly from the more rainy western flank of mountainous coastland or peninsula to the rain-shadow on the eastern side; for in these directions the summer drought increased in length and intensity. The northern mountains, whose rainfall approximated the all-year precipitation of middle Europe, had good and reliable summer pastures which supported herds of horses, cattle and mast-fed pigs, besides flocks of sheep and goats. The southern mountains, located below the 40th or 41st parallel, were covered up to 2,000 or 3,300 feet (600 to 1,000 meters) with the typical thorny and leathery Mediterranean vegetation, varied by occasional groups of deciduous trees growing in deeper pockets of soil, where humus and moisture collected. These lower slopes furnished pasturage fit only for sheep and goats, except in spring and the warm rainy autumn when the short-lived grasses lifted their green stalks.

Above this limit the less fastidious flocks found ampler and better pasturage. Cattle and horses, however, which needed succulent herbage, found suitable grazing only in high level valleys or lake basins which combined deep soil with summer showers, like the lake-strewn highlands of ancient Arcadia and Epirus or the longitudinal valleys of the Apennines. In the more arid southern zone, the best summer pastures were located on westward-facing ranges, like the western Apennines, the mountains of Elis, and the high valleys of "many-fountained" Ida, whose cattle pastures in Homeric days reflected the location of this Mysian mountain between rain-bearing winds from the Aegean Sea and those from the Propontis or Marmora. Mountains or limestone plateaus which barely attained the critical elevation of 3,300 feet (1,000 meters), like the Judean Plateau or the Barca Plateau of northern Africa, yielded ephemeral grasses even on their summits. These countries, therefore, had to restrict the raising of horses and cattle to the scant water-soaked or irrigable lowlands at their base, or draw on the stock of the pastoral nomads along their steppe borders. Only sheep and goats, led about by some boy shepherd of the hills, could thrive on these uncertain upland pastures.

Relation of Stock-raising to Sedentary Agriculture.—Conditions of climate and relief in Mediterranean lands greatly restricted stock-raising as an adjunct of sedentary agriculture. In fact, the two industries were pretty effectually divorced. The flocks and herds fed in winter on the untilled lands, the lowland meadows, and stubble fields of the home farm; but before the advent of summer they were driven out for their half-year on the highland pastures. This is the rule also today. The author has seen sheep feeding on the crest of the Cithaeron range (elevation 2,800 feet or 850 meters) between Attica and Boeotia in early April, while 100 miles farther north the flocks were still grazing on the lake plain of Thessaly, because the middle and upper slopes of the Olympus massif were covered with snow. This divorce of stock-raising from tillage had a marked influence upon the latter. For six months the manure of the flocks and herds was lost to the home fields. To replace it the ancient Mediterranean farmer had to exercise a Chinese-like economy in devising various other fertilizers, even to the ploughing-in of green crops as early as 400 B. C.;[1] but he probably never compensated the soil for the moisture-conserving qualities of the animal manures.

Owing to the lack of home pastures, moreover, the animals kept on the farm were restricted to the imperative needs of agricultural labor, and were stall-fed throughout the year. Their feeding, moreover, called for the utmost economy. The arable land, scant at best because of the predominant mountainous relief, was carefully apportioned to field crops, gardens, fruit orchards, olive plantations and vineyards, according to its suitability for each. Meadows for hay or forage crops could be maintained through the summer only by irrigation; but irrigable fields were scarce and valuable. Natural meadows were confined to wet lands too low to be drained,[2] and were usually of small extent. Fodder crops of great excellence were raised, but forage was doled out to the work animal with a skimping hand. The ancient farmers cultivated various fodder legumes by irrigation during the dry season, reaped several harvests therefrom where the water sufficed, and let the fields serve for green forage during the winter.[3] They relied chiefly on alfalfa or Medic clover (*Medicago sativa*), which was introduced into Greece by the invading Persians in 490 B. C. It yielded four to six crops a year and lasted ten years from one sowing.

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[1] Xenophon, *Oeconomicus*, XVII, 10.

[2] Theophrastus, *Historia Plantarum*, Bk. IV, ch. VIII, 13. Aristotle *De Animalibus*, VII, ch. 23, 6. Naumann and Partsch, *Physicalische Geographie Griechenlands*, p. 404. Breslau, 1885.

[3] Pliny, *Historia Naturalis*, Bk. XVIII, ch. 30–43. Columella, Bk. II, 7 and 10; Bk. V, 12.

To free it from weeds, it was cut close to the ground each spring. The weeds thereby perished, but the alfalfa survived, owing to its deep root system.[4]

Barley and spelt, an inferior wheat, were the feed grains for stock throughout the Mediterranean basin. Rye and oats, which required a moist climate, were for a long time scarcely known. Oats were regarded as a harmful weed in Virgil's time,[5] but a few decades later Columella mentions them as a fodder crop.[6] Rye was raised only in the moister northern parts of the Mediterranean region. Thracians and Macedonians planted it in the 2nd century,[7] and probably earlier, in the 4th century B. C., if Theophrastus is correct. The ancient Taurini, who occupied the upper Po valley about Turin and whose name indicates a cattle-raising folk, raised rye in their well-watered territory.[8] Pliny mentions rye in a mixed fodder crop of rye, spelt and beans,[9] a combination which shows how far the Roman farmers had advanced in the art of feeding cattle, after the enormous grain importations into Italy caused field agriculture to be superseded by stock-raising.

Kind, Number and Distribution of the Animals Raised.—The character of Mediterranean pasturage determined the kind, number and distribution of the animals raised. Pigs were associated with the rainier districts of the north and west, where mast-yielding forests abounded; they were eliminated by climatic conditions from Palestine, Syria, and the semi-arid interior of Asia Minor. In all these regions the climatic inhibition was echoed in a religious taboo. Sheep and goats represented the survival of the fittest for Mediterranean pasturage, and therefore began their successful competition with other kinds of stock at an extraordinarily early date. On the dry fields of Palestine they alone could nibble a living from the poor, thin herbage. Though exempt from farm labor, they furnished milk, cheese, leather, wool and hair for textiles. When slaughtered for meat, their small size was an advantage in iceless homes and in a region where the winter cold rarely sufficed to freeze meat.

Cattle and horses, on the other hand, which required good feeding, were associated even in the time of Homer and Solomon with advanced

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[4] Aristotle, History of Animals, III, 21; VIII, 8. Strabo, XI, ch. XIII, 1, 7. Pliny, Bk. XVIII, ch. 16.

[5] Vergil, Georgic, I, 77. Pliny, Bk. XVIII, 149.

[6] Columella, II, 19, 32.

[7] Galen, VI, 514.

[8] Pliny, Bk. XVIII, ch. 16, 40.

[9] Varro, I, 31, 5. Columella, II, 7, 2. Pliny XVIII, ch. 16, 41.

sedentary agriculture, the possession of marsh meadows, and the maintenance of fodder crops through the dry season by means of irrigation. Their presence reflected quite accurately the geographic possibilities of good or fair summer pasturage. They were therefore rare in Palestine but relatively abundant in Italy, whose long narrow peninsular form, high relief and more northern location curtailed the dry season and insured occasional summer showers, while its extensive plains of moist or swampy alluvium provided conditions for wet pastures in the Po, Arno and Adige valleys and certain coastal lowlands. These conditions also permitted Italy to abandon field agriculture, as opposed to horticulture and viticulture, and to resort to stock raising on a large scale, when Rome's over-rapid territorial expansion and the enormous importation of foreign grain had ruined the small peasant.

Meat Diet in Mediterranean Lands.—The pasturage conditions were further reflected in the amount and kinds of meat used as food in the ancient Mediterranean world. While the flood-plain of the Nile supported cattle, sheep, goats and pigs in relative abundance and supplied meat to the tables of the well-to-do, everywhere else the meat diet was restricted, just as it is today. In Palestine and Greece, a religious festival attended by the sacrifice of a ram, lamb or kid was the chief occasion for the appearance of meat on the table of the common people. These conditions held in Palestine from the earliest times and emphasized the importance of olive oil as a substitute, as revealed all through the Scriptures. The consumption of beef decreased from north to south and from west to east. Except in Italy, it declined also from the earlier to the later epochs with the deterioration of the mountain pastures and the growing pressure of population upon the irrigable lands of the plains. The sustaining food of beef and swine meat which characterized Homeric Greece was greatly attenuated by the 7th Century B. C., and by the 5th century came rarely on the daily table. A goat or a pig was the treat for a festival in Athens, and beef was enjoyed by the common man only at public banquets on the occasion of public sacrifices.[10] Lucky people like the Thessalians and Boeotians, who had good pastures and fat kine in their old lake basins, were scorned as gluttons but were none the less envied. If Solon forbade the sacrifice of an ox for a funeral feast as a sumptuary law in the interest of economy,[11] this prohibition may reflect the increasing price of cattle in Attica, a land poor in pastures.

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[10] E. Speck, *Handelsgeschichte des Altertums*, vol. II, pp. 537-8. Leipzig. 1901, W. S. Davis, *A Day in Old Athens* p. 180. Boston, 1914.

[11] Plutarch, Solon, XXI.

Meat was a luxury for feast days also in the early Republic of Rome; but with the rapid acquisition of more ample and nutritious pastures, as the northern Apennines and the Po valley were conquered and annexed, and with the transition to large-scale stock farming following the second and third Punic wars, beef became a more common article of food; lamb, mutton and goat's meat were cheap, and every form of *porcina* or hog meat was in general demand.[12] Meat figured conspicuously as food among the large patrician and official classes of the capital, where wealth was centralized, and therefore doubtless occasioned the sharp advance in the market price of all cattle which made the older Cato rank stock-raising as the most remunerative branch of tillage;[13] but among the growing proletariat and the vast number of slaves, salt-fish, supplemented by the poorer grades of olives and olive oil, probably took the place of meat, as it did among the common people of Greece.[14] In the early centuries of the Roman Republic, when a balanced system of agriculture prevailed, and at all times elsewhere in the Mediterranean world an immense impulse was given to the ancient fisheries by the need to supply the place of meat. The wide sea ventures of the ancient tunny fleets, therefore, may be regarded as the joint effect of ample coastlines and meager pastures. And when the early Christian church imposed meatless days or fasts upon the Greek and Roman adherents within the Empire, the restriction worked little hardship to the mass of the people, whose dietary stand-by was salt fish. This reflection leaves us with the query how far climatic conditions may discount the merit acquired by certain religious observances.

The scrupulous economy of the grazing and meadow lands in the ancient Mediterranean world reveals itself in various secondary or derivative effects of geographic conditions. Cows and oxen were raised at a minimum cost on the out-pastures of the mountains and marshes, and brought to the home farm when old enough to work. There they were employed for agricultural labor in preference to the horse, which had fewer economic uses and yet required the best feed. We read of ox-wagons and horse-carts in Athens, used to transport building materials to the Acropolis in the time of Pericles,[15] but mules and oxen were more generally employed as draft animals.[16] The unassuming ass was the pack-animal for the rough mountain paths and ill-made

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[12] H. Blümner, *Die Römischen Privataltertümer*, pp. 174–175. Munich, 1911.

[13] Cicero, *De Officiis*, II, 25.

[14] E. Speck, *Handelsgeschichte des Altertums*, vol. II, p. 477. Leipzig, 1901. Boeckh, *Staatshaushaltung der Athener*, Vol. I, pp. 127-130. Berlin, 1886.

[15] Plutarch, Pericles, XII.

[16] A. E. Zimmern, The Greek Commonwealth, p. 270. Oxford, 1911.

tracks which prevailed in the Mediterranean world before the expansion of the imperial road-builders of Rome.

THE HORSE IN MEDITERRANEAN LIFE.—In most Mediterranean lands, horses appear as luxury articles from very early times. Only in the northern and rainy parts of the region, where good pastures were found, did horses become a commonplace. Owing to the cost of raising and maintaining them, they were the luxury of the rich, the special privilege of nobility and royalty, whether among the Jewish kings and princes of ancient Palestine,[17] or the Greek and Trojan chieftains warring on the plains of Ilium;[18] whether among the landed aristocracy of the *Hippobotae* or "horse feeders" of Greek Euboea, or the wealthy class of *Hippes* who constituted the small equestrian order of Athens in the 7th and 6th centuries B. C.,[19] or the *nouveau riche* of Rome who formed the order of the *equites* or knights, among whom the gold ring, the purple-bordered toga and the prancing steed, were the badge of all their tribe. The Eupatrid family of the Alcmaeonides of Athens, like other noble clans of the commonwealth, acquired riches, raised horses on their landed estates, won prizes in the four-horse chariot races in the Olympic Games, and thus arrived at distinction.[20] Vergil specifies the raising of fine sleek-coated horses as the congenial occupation and conspicuous characteristic of the Trojan and Roman nobles.[21] When the poet describes the equestrian evolutions of the Trojan lads at the *Ludus Trojae* or funeral games of Anchises in Sicily, he makes it clear that only the little aristocrats of Aeneas' exile band participated in this miniature cavalry display.[22] Does some such fact as this explain the patrician beauty and noble bearing of the mounted boys in the frieze of the Parthenon? No beggar ever got on horseback in the Mediterranean region: that edifying spectacle was reserved for rainier lands.

Cavalry and chariot service in war became the obligation of the rich, and made horses the concomitant of war throughout the Mediterranean.[23] Aside from their appearance in religious processions, sacred games and races, war was their essential use. The amount of cavalry which each country could command depended upon the supply of wet meadows and therefore often fluctuated with the expansion and

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[17] II Samuel, XV, 1. I Kings, I, 5. Jeremiah, XVII, 25.
[18] J. D. Seymour, Life in the Homeric Age, p. 349. N. Y. 1907.
[19] Herodotus, V, 77. Plutarch, Pericles, XXIII. Aristotle, Politics, VI, 7.
[20] Herodotus, VI, 125. E. Curtius, History of Greece, vol. I, p. 369. N. Y. 1867.
[21] Vergil, Aeneid, VI, 653–655.
[22] Ibid. V, 558–570.
[23] Ibid. I, 444; VI, 653–655. Proverbs, XXI, 3.

contraction of the national frontiers, as the boundaries included or excluded such natural pastures. The few states with abundant and superior pastures became famous for their cavalry and were sought as allies in war; from them horses were purchased or mounted troops were hired by commercial states of large revenue like Athens, which in the days of its wealth could import horse feed. Horses, like cattle, were scarce in Athens, where climate, relief and the composition of the soil were all adverse to good pasturage. Therefore the Athenian cavalry was always small, only 100 to 300 horsemen originally,—a negligible force at the Battle of Marathon,—and never numbering more than a thousand, who were occasionally reinforced by mounted Scythian bowmen.[24] Hence the Athenian state, in the protracted wars with its rivals, always sought the alliance of the few Greek commonwealths which had a numerous cavalry.

The prevailing rugged relief of the Mediterranean lands tended to restrict the employment of cavalry and chariots in war, and in some districts quite inhibited their use. It dictated the choice of broad and level battlegrounds by generals with strong mounted forces, who therefore manoeuvred for place. Thus the northern Syrians and Philistines, who had numerous chariots, drew the horseless Israelites into battle in the lake-plain of Merom and the plain of Esdraelon.[25] The Persian invaders of Greece in 490 B. C. selected the plain of Marathon for their decisive battle, by the advice of the traitor Hippias, and later the plain of Platea, because the defending forces were weak in cavalry and the Persians were strong.[26] Attica was not a country whose terrain permitted the free operation of mounted troops, but Boeotia was;[27] hence the significance of the battle fields of Chaeronea and Coronea, located in lake and valley plains of Boeotia, for the Macedonian conquest of Greece. Hannibal, on his invasion of Italy, could employ his Numidian cavalry to an advantage in the broad Po lowlands at Ticinus and Trebia, the lake plain of Trasimenus and the coastal plain of Apulia at Cannae. When caught by the Romans in a mountain valley where his cavalry was useless, he escaped from the trap by strategy.

Economy of Pastures and Improvement of Animal Breeds.—The paucity of the Mediterranean pastures necessitated their intelligent and economic use. This requirement led to the improvement of the animal breeds by artificial selection at an early period, in Egypt

[24] A. Boeckh, *Die Staatshaushaltung der Athener*, vol. I, pp. 330-333. Berlin, 1866.
[25] Joshua, XI, 4, 5. 1 Samuel, XIII, 5. Judges, IV, 3; V. 19–22.
[26] Herodotus, VI, 102.
[27] Herodotus, IX, 13.

even under the old Empire in 3,000-2,500 B. C.[28] It was well established in Greece in the time of Aristotle or earlier; it developed into a broadly applied system in Italy and Sicily, and appeared in Cyrene, Africa and Spain. The process was fostered by the early live-stock trade, due to the uneven distribution of pasturage, which sprang up between districts of good and poor grazing. Surplus animals from all the pastoral hinterlands reached the Mediterranean markets where they were exchanged for grain or manufactured commodities. Occasionally they came as tribute; and since the kind and breed of animals were generally specified by the law imposing the tributes, such animals were probably the best of their kind. This was particularly true in the case of horses. Overseas trade in live-stock was facilitated by the early development of horse transports as a branch of the merchant marines of both Phoenicia and Greece. Aside from the imperative need of transporting cavalry for war, which was well established by 490 B. C.,[29] the risk and expense of taking animals on long voyages in small boats must have been prohibitive except for choice specimens which would command high prices; and these would naturally be used for breeding purposes. We hear of Venetian horses in Sparta in the middle of the 7th century B. C.[30] Fine horses and mules of racing stock were brought from African Cyrene and various cities of Sicily as early as 494 B. C. to compete in the sacred games of Greece at Corinth, Delphi and Olympia.[31] It is easy to imagine that the sacred precincts of the games became the scene of busy horse trading after the prizes had been awarded, and that thus various strains were mixed and eventually improved.

The evidence points to a very early importation of the superior Thracian horses into Italy. Vergil would hardly have dared to make Aeneas find Thracian horses the property of the local kings in Sicily and Latium,[32] if the anachronism had been all too violent. The fact that the Carthaginians employed horse transports in 488 B. C. in a military expedition to Sicily[33] suggests that they may have earlier imported choice animals from Phoenicia to stock their big landed estates in Africa, as is indicated in the Aeneid when Dido presents the boy Ascanius with a fine Sidonian steed.[34] The nature of the horse as a luxury article and its highly specialized use for chariot

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[28] Erman, Life in Ancient Egypt, pp. 436-438. London, 1894.
[29] Herodotus, VI, 95; VII, 87, 97.
[30] E. Speck, *Handelsgeschichte des Altertums*, vol. II, p. 483. Leipzig, 1901.
[31] Pindar, Odes, Pyth. I, II, III, VI; Olym. I-III, VI; Nem. IX.
[32] Vergil, Aen. V, 565–567.
[33] Diodorus Siculus, Bk. XI, chap. II.
[34] Vergil, Aen. V, 571.

races and war, requiring speed and endurance, doubtless contributed to the early improvement of the equine strains through artificial selection, and therefore to a peculiarly discriminating trade in the animal. The horse breeds were improved also by superior feeding, by the reservation of the best green pastures for the mares and colts, and by the maintenance of stud-farms at great distances, wherever natural pastures afforded green fodder all year round. This was noticeable among Macedonian, Greek, Sicilian, and Roman nobles and plutocrats.

Regions of export for selected breeds of horses and cattle were characterized by marsh-meadows, heavy rainfall with summer showers, or by the moist soils of lacustrine basins surrounded by high mountains. Such regions were Egypt and the Cilician lowland; Thrace, Thessaly, Messinia, Arcadia, Elis, Argos and Epirus in Greece; Apulia, the Po valley, and Venetia in Italy, together with Sicily. In the Iberian peninsula only the Guadalquiver lowlands or Baetica had attained a sufficiently advanced economic development to yield superior breeds.

The best sheep and goats were sought for breeding purposes in regions of dry pasturage near old industrial centers famous for their textiles, like Miletus, Megara, Athens, Tarentum, Corduba and Gades. These districts had selected their breeds for the fineness, length and color of their wool or hair; and further to improve the quality of the fleece, they covered the sheep with skins.[35] Diogenes said that the children of the Megarans ran about naked, while their sheep were clothed. This trade in improved strains began very early. We read, for instance, that Polycrates of Samos (532 B. C.) imported goats from the islands of Naxos and Scyros, sheep from Attica and Miletus, and swine from Sicily.[36] The demand for wool and goat's hair for textiles was imperative. Cotton was as yet unknown to the Mediterranean farmers, and the cultivation of flax for fibre was practically restricted to Egypt for centuries, for there chiefly was found the rich, moist alluvial soil which it required. Such soil was found in other Mediterranean lands in limited quantities, and seldom could it be spared from the more important wheat, especially since both Hebrew, Greek, and Roman farmers knew that flax exhausted the ground.[37] Therefore flax culture came late into Italy and then was centered in the alluvial plains of the Po valley.[38] Linen was sparingly used for

[35] H. Blümner, *Gewerbe und Kunst bei Griechen und Römern*, vol. I, pp. 91–98, Leipzig, 1875.

[36] Athenaeus, XII, 57.

[37] H. Vogelstein, *Landwirthschaft in Patästina zur der Mischnah*. Berlin, 1894. Columella, II, 10, 17. Theophrastus, *De Causis Plantarum, IV*, 5, 4.

[38] Pliny, XIX, 9.

clothing even in the first century of the Empire, when it was a luxury article for the Caesars and the rich.[39] In contrast, every rocky island unfit for tillage supported flocks of goats, while goats and sheep flecked every mountain side in summer, and drifted over every plain and hill in winter.

Let us now examine the various Mediterranean countries in the light of these general principles, and get the picture of stock-raising in each from the data which have come down to us.

Stock-raising in Egypt.—Ancient Egypt had cattle and horses in abundance both for home use and export. In time of famine they were exchanged for the government grain under Joseph's rule.[40] To the Greeks the Nile was "the stream where graze the goodly kine."[41] Compare the vision of Pharaoh before the seven year's famine: "There came out of the River seven well-favored kine and fat-fleshed, and they fed in a meadow."[42] The inundations of the Nile irrigated an area large enough both for plough land and pasture. Moreover, the marshes of the Delta, which remained unreclaimed long after the river valley proper had been brought under cultivation and which were in part unreclaimable, furnished natural pastures when the fodder supply in the farm land ran low, prior to the summer flood. Thither the cattle were driven from the south every year, and were entrusted to the local marsh-men. These were an uncouth people but professional herdsmen; they still persisted as such in the time of Marcus Aurelius (180 A. D.), when the Romans called the marshes of the Delta the *bucolia* or cattle pastures.[43] The Nile valley furnished various irrigated forage crops, which fed the home cattle and horses penned up in the mound villages during the summer floods.[44] Under these favorable geographic conditions, Egypt from 3000 B. C. maintained a careful system of cattle-breeding, which resulted in several varieties of ordinary and humped cattle;[45] and it supported the horse-breeding industry which supplied an export trade to Palestine, Syria and the Hittite country of Asia Minor.

The Egyptian horses were carefully bred and were evidently superior to the native stock of south-western Asia, because they commanded

[39] H. Blümner, *Die Römischen Privataltertümer*, p. 241. Munich, 1911.

[40] Herodotus, II, 37; Genesis, XLVII, 15-18.

[41] Aeschylus, The Suppliants, 834.

[42] Genesis, XLI, 2.

[43] A. Erman, Life in Ancient Egypt, pp. 439-444. London, 1894; Mommsen, Provinces of the Roman Empire, Vol. II, p. 284. New York, 1887.

[44] Diodorus Siculus, Bk. I, ch. III, 36.

[45] A. Erman, Life in Ancient Egypt, pp. 436-437. London, 1894.

high prices in export. The large number of chariots and cavalry in the Egyptian Armies from the 14th century, B. C. indicates horse-raising on a big scale. This was rendered possible by the ample grain and fodder crops of the Nile valley, and in turn it rendered possible the broad artificial selection which improved the breed. The original equine stock came in with the Hyskos invaders (1700 B. C.), but it was probably improved by crossing with the fine horses of the Libyan tribes, who began pushing into the western margin of the Delta from the 13th century. These nomads, like the later Bedouins, apparently developed an animal distinguished by speed and endurance, in response to the requirements of thinly scattered pasturage, desert warfare and border raids. The excellence of this Libyan breed reappeared in the race horses of Cyrene, which frequently carried off the prizes in the Olympic Games.[46]

Stock-raising in Palestine.—Palestine, because of its climate, geology, relief and the deep Jordan rift which makes the highland over-drained, has always had scant natural grazing for cattle and horses, though sheep and goats can find enough forage of a poor kind. But flocks and herds alike suffered from the frequent droughts or half-droughts which visited the land, when cow and ewe, like the hart, "panted for the water-brooks." The ancient breed of sheep was undoubtedly the broad-tailed variety, which probably came from arid Asia by way of Arabia.[47] It was fortified against a season of poor pasturage by the store of fat in the immense tail, translated "rump" in the Bible but now given as "fat tail" in the revised version.[48] The limestone plateau of Judea and the lower Negeb to the south were covered with herbage after the March rains, and furnished a nutritious but transitory pasturage. Here in the spring grazed "the cattle upon a thousand hills" of which the psalmist sang[49] with more religious fervor than scientific accuracy. By midsummer all was parched and brown. Earlier still faded the belt of green to the east and south, the short-lived "pastures of the wilderness."[50] The flood plain of the lower Jordan, which the sheik Lot selected for his portion of Palestine because it was well-watered, was indeed saturated with moisture after the melting of the snows on high Hermon (8,700 feet or 2,653 meters)

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[46] O. Keller, *Die Antike Tierwelt*, Vol. I, pp. 219-221, 1909. W. Ridgeway, Origin and Influence of the Thoroughbred Horse, pp. 216-223. Cambridge, 1905.

[47] Herodotus, III, 113.

[48] Exodus, XXIX, 22; Leviticus, III, 9.

[49] Psalms, I, 10.

[50] Joel, I, 18–20.

to the north; but its grass soon perished in the furnace heat of the deep rift (1,293 feet or 394 meters below sea-level).

Only on the narrow coastal plain of Sharon and the valley floor of Esdraelon did the grass never wholly fail in summer. These therefore were the chief natural pastures for the cattle of King David.[51] Both districts are fed by springs from the porous limestone plateau and have a high water-table which ensures a modicum of moisture to their soil. Sharon extends 50 miles from Joppa to Carmel, with a varying width of 6 to 12 miles. Swamps half a mile wide border its streams, whose outlets are obstructed by the coastal dunes, and many small lagoons are strung along its shore. Sharon is today a district of pastures and scattered farms, between which stretch belts of evergreen oak, the remnant of the forest described by Strabo and Josephus.[52] Much of it was under cultivation in ancient times, but the remainder yielded the best pasturage of Palestine and nourished superior cattle, which are praised in the Talmud.[53] The old lacustrine plain of Esdraelon, surrounded by Mount Carmel and the hills of Samaria and Galilee, located farther north than Sharon and better watered, is a natural meadow land. Its broad, level floor lies so little above sea-level and has such a slight drainage slope that much of it is marshy during winter and spring, so that the modern road crosses it on a dyke. This is the plain where Sisera and his 900 war chariots got mired during a battle when the Lord sent a sudden storm to assist the Israelites.[54] The value of these wet meadows was recognized in ancient Palestine. "Blessed are ye that sow beside all waters, that lead out thither your ox and your ass." The Bible gives a picture of poor and uncertain grazing for the larger animals elsewhere west of Jordan. Allusions to "fat pastures" and "large pastures" occur only when the prophets, in rare moments of optimism, indulge in hyperbole to describe the material blessings promised to a repentant Israel[55] by an irascible deity, whose moods varied with the weather, not as an effect but as a cause.

East of Jordan, the plateau belt of Gilead, Golan and Bashan rises 2,600 to 4,400 feet (800 to 1,300 meters) above the sea, and receives from 16 to 24 inches (400 to 600 mm.) of rainfall in Golan, but less in Gilead to the south.[56] This sufficed in ancient times, as

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[51] I Chronicles, XXVII, 29.

[52] General Staff Map, No. 2321, Jaffa Sheet. E. Banse, *Die Turkei*, p. 371, Braunschweig, 1919.

[53] Hastings, Dict. of the Bible, article Sharon. Isaiah, XXXV, 2; LXV, 10.

[54] Judges, IV, 3, 13; V. 19–22.

[55] Ezekiel, XXXIV, 14. Isaiah, XXX, 23.

[56] E. Banse, *Die Turkei*, pp. 361-362. Braunschweig, 1916.

today, for good or even excellent grasslands,[57] over which cattle wandered in a half-wild state in charge of nomadic herdsmen. Such were the "bulls of Bashan" and the herds whose yield figured in the tribute paid to the kings of Israel and Judea, and in the produce sent to the western markets. This district furnished booty in the form of cattle to the Israelite conquerors;[58] and it was appropriated by the tribes of Gad who were essentially herdsmen.[59]

The small natural meadows of ancient Palestine seem to have been reserved for the cows and oxen which performed the farm labor of ploughing and treading out the grain, and which served also for food and religious sacrifices. There is little evidence of efforts to improve breeds. Cows were kept to maintain the supply of oxen; their milk-giving ability was small, owing in part to the inferior pasturage and their constant labor. For the same reasons the cattle were small and short-limbed, but tolerant of the harsh conditions.[60] The regulations of Leviticus, which exacted victims without blemish for sacrifice in the temple, may have been an adroit priestly method to encourage discriminating breeding; but this was possible only to a limited degree, since the majority of the stock ran free on the highland or lowland pastures.

Horses in Palestine.—Nowhere else were horses so great a luxury as in Palestine. Before the Jewish conquest, the Philistines of the coastal plain had numerous horses and chariots,[61] and so had the Canaanites who occupied the plain of Esdraelon and the moist lake-basin of Merom;[62] but the native tribes of the upland seem to have had none. When the Israelites invaded Palestine and established themselves on the rugged Judean plateau, they saved the cattle taken in their conquest, but were instructed to hamstring the horses,[63] because the land afforded no suitable pasturage. The earliest laws, embodied in the book of Deuteronomy, were the result of about three centuries of practical experience in Palestine. They forbade the kings to breed horses or to import them from Egypt for breeding purposes.[64] But later, when David and Solomon had extended the frontier of their domain from the Mediterranean coast to the Arabian Desert, and northward to the great bend of the Euphrates, the pasturage situa-

[57] Libbey and Hoskins, The Jordan Valley and Petra, vol. I, pp. 107–8. N. Y. 1905.
[58] Deuteronomy, III, 7–8.
[59] Numbers, XXXII, 1–5.
[60] Hastings, Dict. of the Bible, art. Food.
[61] Judges, I, 19.
[62] Joshua, XI, 4–7, 14.
[63] Joshua, XI, 9, 14.
[64] Deuteronomy, XVII, 16.

tion was improved, because the kingdom included the plains of Sharon, Esdraelon, and Coelo-Syria, the broad fertile valley between the Lebanon and Anti-Lebanon Mountains, which provided both natural and irrigable meadows.

David deviated from the old rule after his victory over the northern Syrians by reserving from the booty horses for a hundred chariots[65] or probably three hundred animals. All the rest he disabled. Solomon went into horse-breeding on a large scale and made it a royal monopoly.[66] He received both horses and mules as tribute, doubtless from Gilead and Damascus, where the kings had chariots[67] and also from the northern Syrians; and he imported from Egypt droves of horses at a cost equivalent to $100 per head, to supply the cavalry and chariot corps of his army,[68] which was enlarged to protect the wide frontiers of the new Empire. From this time horses were royal beasts, associated with war. They were chiefly stall-fed on barley and straw.[69] The temporary expansion of the Jewish kingdom to the Mediterranean gave Solomon control of the great caravan route along the maritime plain, and made him the sole middleman in the horse trade between Egypt and the Syrian and Hittite kings of the north.[70] The Tel Amarna letters indicate that these rulers made an active demand for the Nile horses, which were doubtless a superior breed. Solomon also purchased stallions from Cilicia, probably to sell them again to Egypt to improve the strain there.[71] Lowland Cilicia, located between Mt. Amanus and the Taurus system, was a broad, well-watered alluvial plain, abounding in marsh meadows. As its tribute to Darius the Persian in 500 B. C. consisted of 360 white horses,[72] its equine breed was probably superior. After the division of the Jewish kingdom, the plains of northern Palestine or Israel continued to raise horses, but rugged Judea had to rely on importations from Egypt, despite the protests of the prophets.[73]

Stock-raising in Phoenicia and Syria.—Narrow, rugged Phoenicia, with its terraced mountain sides devoted to gardens and orchards, offered little feed or pasturage for animals, and little opportunity for their employment. Hence cities like Tyre and Sidon imported sheep

[65] II Samuel, VIII, 3–4.
[66] I Kings, X, 25–26.
[67] II Kings, IX, 16, 20; V. 9.
[68] I Kings, X, 28–29. II Chronicles, IX, 28.
[69] I Kings, IV, 28.
[70] I Kings, X, 28–29.
[71] Maspero, Struggle of the Nations, pp. 215–216, 739–740. N. Y. 1897.
[72] Herodotus, III, 90.
[73] Isaiah, XXXI, 1. Ezekiel, XVII, 15.

and goats from the nomad tribes of Kedar in northern Arabia, and wool from Damascus. From Armenia (Togarmah) they bought war horses and mules,[74] which they probably sold again farther south in Palestine or Egypt. Armenia was a famous horse-breeding region in ancient times and used to pay to the Persian kings an annual tribute of 20,000 foals[75] which fed on its high Alpine pastures in summer, and in winter on the produce of its fertile valleys, as the horses of the wandering Kurds do today. The hinterland of the Phoenician seaboard was Coelo-Syria or the Lebanon trough, which afforded the largest and best pasture area of all Syria. The trough, which forms a broad U-shaped valley of gentle gradient, is drained by the Leontes and Orontes rivers, which rise in a swampy, indeterminate watershed near Baalbek at an altitude of 3,500 feet. The Orontes, the longer stream, takes a leisurely course northward through an almost level plain, and at intervals spreads out in broad shallow pools, bordered by marshes,[76] which in ancient times created extensive meadows for horses and cattle. Reclaimed in part for irrigated fields, the plain fed the ancient populations of Kadesh, Hemesa (Homs), Hamath, Apameia and Antioch.[77] After Alexander's conquest of Syria, the wet meadows formed by the Orontes near the city of Apameia were selected for the royal Macedonian stud-farm, which kept 30,000 brood mares and 300 stallions.[78] This is part of that Syria whose chariot and cavalry forces wrought havoc among the armies of the Kingdom of Israel.

Stock-raising in Asia Minor.—Asia Minor, owing to its more northern location, its peninsula form and high elevation, had a well assured rainfall along its coasts, especially on the west and north where the precipitation ranged from 25 to 40 inches (625 mm. to 1,000 mm.). In the mountain rimmed interior of the plateau, steppes and salt deserts prevailed, where cattle, wild asses and sheep roamed at large over dry or saline pastures,[79] or in summer ascended the inner valleys of the encircling mountains as they do today.[80] The products of this semi-arid hinterland were probably one source of the fine wool which through the ages has sought the industrial cities of the Aegean littoral and supported their textile industries. Phrygia Major, which lay just east of Lydia at the head of the mountain valleys opening westward

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[74] Ezekiel, XXVII, 14, 18, 21.
[75] Herodotus, V, 49. Strabo, XI, ch. XIV, 4, 9.
[76] E. Banse, *Die Turkei*, pp. 315, 333-338. Braunschweig, 1916.
[77] Mommsen, Provinces of the Roman Empire, vol. II, p. 148. N. Y. 1887.
[78] Strabo, XVI, ch. II. 10.
[79] Strabo, XII, ch. II, 7, 9; ch. III, 8; ch. VI, 1.
[80] Banse, *Die Turkei*, pp. 98-114.

to Aegean winds, got hardly less rain than the coastal belt (400-500 mm.),[81] and therefore, Herodotus says, was famous for its wheat and cattle among the ancient Greeks of Ionia and the Carian seaboard. Cappadocia comprised the high eastern portion of Anatolia, 3,300 feet or 1,000 meters, and included in its area the lofty *massif* of Mount Argaeus (13,000 feet or 4,000 meters), an old volcano, whose lower slopes and piedmont, covered with a rich soil of weathered trachyte, tufa, and lava, merge into the fertile fields and meadows of Caesarea.[82] This region produced the immense number of horses, mules and sheep sent yearly as tribute to the Persian kings, and the famous Cappadocian race-horses of the Roman Circus.[83]

Western Asia Minor was a part of the ancient Aegean world, so far as its broad embayed littoral was concerned. Its early activities in stock-raising are therefore interwoven with those of the Greek people, by whom it was colonized. In the Iliad and Odyssey, horses and cattle belonged to sedentary agriculture, which presupposed irrigated fodder crops and wet meadows, and they therefore shared the honor due to the highest civilization of Homeric times.[84] But their distribution around the Aegean circle of lands shows a close connection with geographic conditions. Saturated river lowlands, deltaic flats, and lacustrine basins seem to produce horses and cattle as naturally as the reeds growing in the moist soil. In such places were found the flowery meadows and level stretches of rich soil which the Homeric Greeks loved for their cattle and horses.[85] Beside every green pasture was the meandering brook or reedy pool, recalling the *prata recentia rivis* of Vergil.[86] "The kine that are feeding innumerable in the low-lying land of a great marsh" give us the typical picture,[87] or the horses of Achilles "cropping clover and parsley of the marsh" on the Troad coast.[88] Of a Trojan prince we are told, "Three thousand mares with their colts had he, that pastured along the marsh meadow," where the Simois and Scamander rivers had deposited their silt on the flat coast,[89] forming swamps and lagoons about their obstructed outlets.[90] Enops tended "his herds near the banks of the Satnoeis,"

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[81] Ibid. p. 114.

[82] Ibid. pp. 98-104.

[83] Strabo, XI, ch. XIII, 8; XII, ch. II, 10. O. Keller, *Die Antike Tierwelt*, Vol. I, p. 225. Leipzig, 1909.

[84] A. G. Keller. Homeric Society, pp. 20–21, 33–37. N. Y. 1902.

[85] E. Buchholz, *Homerischen Realien*, vol. II, pp. 137–139. Leipzig, 1881.

[86] Vergil, Aen. VI, 674.

[87] Iliad, XV, 630–632.

[88] Iliad, II, 775.

[89] Iliad, XX, 221–222.

[90] Strabo, XIII, ch. I, 31, 36.

where this stream watered another meadow for the horse-taming Trojans.[91] Farther south on the Aegean coast of Asia Minor, Homer observes "the wild geese or cranes or long-necked swans on the Asian meadow about the streams of Cayster,"[92] where the river meanders through its alluvial plain to the sea.

The Troad and Phrygia Minor to the north, located between the Aegean and the Propontis or Marmora, receive rain-bearing winds from both seas. Especially the Pontic clouds condense on the successive tiers of east-and-west ranges, which increase in altitude towards the high crests of Mount Ida and the Mysian Olympus in the south. A rainfall of 32 inches (800 mm.), fertile valley floors of alluvium, rich moist meadows, and swampy lakes formed by the streams dammed by the coastal hill ranges, combined to make admirable conditions for tillage and stock-raising here in ancient times as today.[93] Therefore Abydos and Percote on the Hellespontine shore had "pastures for swift mares" and for oxen;[94] and the Adrasteia plain, through which the Granikos flowed, was a natural pastureland praised by Homer. Nearby "many-fountained Ida,"[95] exposing a long flank to the Pontic winds and rains was wont to echo with "the lowing of herds and the bleating of sheep."[96] Farther east Asia Minor presents a continuous front of high forested mountains to the Pontic winds; but wherever a longitudinal trough like the Salon valley of northern Bithynia provided a level surface, or a river like the Iris or Phasis succeeded in building a small delta on this steep coast, where nature's irrigation overcame the summer drought,[97] there we hear of highly valued pastures for cattle and horses, of cows famous for their milk,[98] and of choice cheeses which entered the markets of the Mediterranean world.[99] So rare were good pastures that they were never overlooked by the ancients, even though small in area. Significant is the fact that these ancient meadows are districts of cattle production today. Such is the ancient Salon or modern Boli valley of Bithynia.[100]

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[91] Iliad, III, 250; XIV, 443.

[92] Iliad, II, 460–461.

[93] Banse, *Die Turkei*, pp. 65–71.

[94] Iliad, II, 819; XV, 546.

[95] Iliad, XIV, 283.

[96] Sophocles, Niobe, quoted in Strabo, XII, ch. VIII, 21. Iliad, II, 749; V. 315; XXI, 448.

[97] Strabo, XII, ch. III, 15.

[98] Aristotle, *De Animalibus*, III, ch. XXI, 17.

[99] Strabo, XII, ch. V, 7. Pliny, XI, ch. 97.

[100] Banse, *Die Turkei*, p. 80.

Horses in Thrace.—Thrace was famous for its horses from Homeric times. The great quarternary plain of eastern Thrace was probably too dry in the summer, as it is today, to provide proper pasturage for horses. However, the long southern littoral from Lake Stentoris and the mouth of the Hebrus River (Maritza) west to the Axius (Vardar) was a succession of lakes, lagoons, marshes, and brackish pools, and of alluvial lowlands, flooded at intervals by the mountain streams draining from the lofty Rhodope highlands,[101] and possessing every geographical feature for wet pastures. Diomedes, whose horses figured in the Trojan War and in the adventures of Hercules, ruled over the plain of Lake Bistonis with its city of Abdera, a region lying so low that Hercules was able to flood it by cutting a canal to the sea.[102] The horses of the Thracian Rheseus were the finest, swiftest and whitest ever seen by Trojan or Greek. Two herds of chestnut horses formed part of the dowry of a daughter of King Cotys of Thrace in the 4th century B. C.[103] Cavalry constituted an important feature of the Thracian army from the time of the Peloponnesian War down to that of the Roman Caesars, and made it a valuable ally in war.[104] In Strabo's time the Thracian cavalry numbered 15,000, and the infantry 20,000, an unusual proportion.[105] Thracian horses were early imported into Italy and Sicily, and the peculiar markings of the Thracian breed were well known.[106] White horses were brought to Rome for sacrifices and also to carry the victorious consuls in the public triumphs. After the Macedonian conquest, Thracian cavalry was incorporated in the mounted forces of Philip the Great, which were already strong. For Macedon has ample meadows in the broad alluvial plain of the Axius River, and excellent summer pastures in the northern mountains, whence came the Paeonian cavalry. Moreover, Philip imported 20,000 fine mares (*Nobilium equarum*) from the lower Danube Plains to improve his stock and probably introduced Thracian, Thessalian and Epirote strains for the same purpose.[107]

Stock-raising in Greece.—In Greece proper only a few localities afforded suitable pastures for horses and cattle, especially in the more arid eastern part of the peninsula, which was cut off by mountain ranges from the rain-bearing winds from the west. In this populous and progressive eastern part, cattle or their products were imported from the

101 Herodotus, VII, 58, 109, 124.
102 Iliad, XIV, 225-227. Strabo, Fragment, 44, 47, 48.
103 Athenaeus, Bk. IV, 7.
104 Mommsen, Provinces of the Roman Empire, vol. I, p. 226. N. Y. 1887.
105 Strabo, Fragment, 48.
106 Vergil, Aen. V, 565.
107 O. Keller, *Die Antike Tierwelt*, Vol. I, p. 227. Leipzig, 1909.

steppes of far away Scythia, Africa and from Macedonia[108] to supply the local demand. The best and largest pastures were to be found in the broad lacustrine basin of Thessaly, which was alternately flooded and drained by the Peneus River system. This region repeatedly furnished cavalry for Athens from the days of Pisistratus,[109] and provided horsemen for Alexander's army in his conquest of Asia. In all Greek wars its alliance was sought because of its mounted troops. The Thessalian horse was a superior animal, the product of good feeding, of broad artificial selection made possible by large numbers, and of free movement over wide plains, whether he was grazing, training for races, or practising in cavalry manoeuvers. Therefore Sophocles makes Orestes enter the Pythian Games with a span of Thessalian steeds. A Thessalian stud farm at Pharsalus, on the southern margin of the lacustrine basin, bred Alexander's famous horse Bucephalus.[110] Aristotle in his Politics attributed the strong oligarchy which always ruled Thessaly to the adaptation of the country to horse-breeding, and the consequent concentration of cavalry forces in the hands of rich landowners. Homer praises "the oxen, horses and harvests of deep-soiled Phthia"[111] whose pastures bred the steeds of Achilles. This region comprised the shelving coast of the Pegasae Gulf and the alluvial valley of the Sperchius River, whose broad flats along the sea, always soaked and always growing by annual accretions of silt farther out into the Malic Gulf, must have furnished excellent wet meadows for the ancient warlord as for the peasant of today. Across these fens of the Sperchius the modern carriage road runs for five miles on the top of a dyke, pierced at intervals to let the distributaries flow out to the sea, whose low shoreline is faintly visible several miles to the east. The growth of the half-fluid soil went on in Homeric times as today and provided perennial meadows. The scene embossed on the shield of Achilles may have been taken from his home country. It depicted a herd of kine: "lowing they hurried from the byre to pasture beside a murmuring river, beside the waving reeds," invariable marks of swamp vegetation.[112]

Horses in Hellas.—Aside from the Sperchius valley plain, which was the borderland of ancient Thessaly, Hellas proper could show only one region of excellent pasturage, and that was the moist lacustrine basin of Boeotia. Its early preëminence in horse breeding was based upon the rich pastures of "grassy Haliartus" on the reed-grown

[108] Herodotus, VII, 126. IV, 1-12. Polybius, IV, 38.
[109] Herodotus, V, 63. Thucydides, I, 102, 107; II, 22.
[110] Arrian, Anabasis, V, 19, 5.
[111] Iliad, I, 154.
[112] Iliad, XVIII, 573–576.

margin of Lake Copais,[113] and "Graia and Mycalessos with their wide meadows" in the valley of the River Asopus.[114] Therefore Boeotia was chief "of all the lands far-famed for goodly steeds."[115] This reputation, voiced by Sophocles, is repeated three centuries later by Dicaearchus.[116] And Thucydides states that only Boeotia, Phocis and Locris furnished the cavalry of the Spartan allied forces during the Peloponnesian War.[117] Phocis comprised the northern portion of the fairly broad valley of the Cephissus River, which continues southward as part of the Boeotian plain. It is rather a significant coincidence that the author, in a recent motor trip through Greece, met groups of horses only in Boeotia, the Cephissus valley of Phocis, and in Thessaly. The cavalry of Locris must have depended upon the small but fertile coastal plain of Opous along the Euboean Sound. The location of these cavalry states was ominous for Greece. At the battle of Plataea, as described by Herodotus, the allied Hellenic states had no mounted troops, because the invading Persians conquered or conciliated all the "horse" country to the north through which they marched.[118] Attica, as we have seen, had no pasture land and very slowly developed a limited force of cavalry. The conquest of the lower Asopus plain from Boeotia and the acquisition of the island of Euboea with its good pastures, once famous for their horses and cattle,[119] may have helped Athens maintain its thousand horsemen.

Stock-raising in the Peloponnesus.—The Peloponnesus contained little territory suited to cavalry movements. This fact partly explains the scarcity of mounted troops in the peninsula, whose wars were largely border conflicts along the high mountain boundaries of the several states. Such were Sparta's wars with Messenia, Argolis and Arcadia. "Argos pasture land of horses," which comprised the small silted plain at the head of the Argolic Gulf, and the valleys of Homeric Sparta, which included both Laconia and Messenia, were famous for their meadows and their equine stock.[120] The boy Telemachus, coming from the rugged isle of Ithaca, admired Sparta's "open plains where clover is abundant, marsh-grass and wheat and corn and

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113 Theophrastus, *Historia Plantarum*, IV, ch. X, 7. Iliad, II, 503. Strabo, IX, ch. II, 18.

114 Iliad, IV, 499. Strabo, IX, ch. II, 10–11.

115 Sophocles, Edipus Colonus, 668.

116 Quoted in J. G. Frazer, Pausanius, Introduction, p. XLV. London, 1898.

117 Thucydides, II, 9.

118 Herodotus, IX, 19–20.

119 Ibid. V, 77.

120 Iliad, III, 74; IV, 530.

white-eared barley,"[121] and he received from King Menelaus a pair of horses as a gift. But the valley plain of the Eurotas River contains only about 40 square miles of level land "lying low amid the rifted hills;" it is shut off from the sea by a broad limestone ridge through which the little stream has cut its course to the Laconic Gulf. This plain had to suffice for both plough and pasture land for the Spartans of the historical period, till they conquered Messenia about 600 B. C.

It is easy to see the growing pressure of population upon the limits of subsistence in this secluded valley, the consequent substitution of hoplites or spearmen for cavalry as the main force of the Spartan army,[122] and the conquest of Messenia as a piece of necessary territorial expansion, all at about the same time. In this connection consider the further fact that the Eurotas valley, lying far south and in the rain-shadow of the lofty Taygetus Mountains, receives only 20 inches of rain (500 mm.) and endures four months of summer drought. Significant is the fact that the first Messenian war arose from a border quarrel, evidently about some pastures on a high, water-soaked moor (a common Alpine phenomenon), located west of the Taygetus crest, where the Spartans had set up a shrine or temple to Artemis Limnates or Artemis of the Marshes,[123] possibly to sanction their encroachment on Messenian territory. This Artemis was a goddess of fertility, worshipped in swampy or moist alluvial spots which were conspicuous by their succulent green herbage in the dry brown landscapes of the Greek summer.[124]

Messenia's extensive alluvial plains and her location on the windward side of the Taygetus range insured for her fairly abundant moist meadows. Here were " grassy Hira, divine Pharae, and Antheia deep in meads " all located on the deltaic flats along the Messenian Gulf.[125] The modern Kalamata, on the site of ancient Pharae, gets an annual rainfall of 39 inches (980 mm.),[126] and occupies a plain irrigated by the Nedon River, draining from the Gomo peak (4,165 feet or 1,277 meters) of the Taygetus range. Therefore ancient Messenia was famous for its cattle and horses.[127] We even hear of its selling a shipload of horses to Egypt in the third century B. C.[128]

Messenia shared the advantage of an ampler rainfall, coupled however with a long summer drought, with all western Peloponnesus and

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121 Odyssey, IV, 602–604.

122 J. B. Bury, History of Greece, p. 129. London, 1909.

123 Tacitus, Annals, IV, 43. Pausanius, III, ch. VII, 4; IV, ch. XXXI, 3.

124 M. P. Nilsson, Griechischen Feste, pp. 214–216. Leipzig, 1906.

125 Iliad, IV, 291. Strabo, VIII, ch. IV, 1, 5.

126 A. Philippson, *Europa*, p. 284. Leipzig, 1906.

127 Strabo, VIII, ch. V, 6.

128 Polybius, V, 37.

Hellas north to the Gulf of Ambracia (Arta) and the borders of Epirus, where summer showers begin. The broad Tertiary plain of Elis, watered by the Alpheus and Peneus rivers, and dotted with lagoons along its coastal belt, contained the best lowland pastures of the Peloponnesus.[129] Here grazed the cattle from the stables of King Augeus and the famous horses of Nestor of Pylus,[130] the king who in a cattle raid on the neighboring city of Elis drove off 50 herds of kine, 50 flocks of sheep, 50 flocks of goats, and 150 mares with their foals.[131] There followed a punitive expedition by mounted Eleians and a battle in which horses and chariots were part of the booty,[132] fought out on the level plain of the Alpheus. When Philip V. of Macedon invaded the Peloponnesus in 218 B. C. and violated the sanctity of sacred Elis, he secured an immense amount of cattle.[133] Today, the little town of Gastouni near the mouth of the Peneus, only six miles from the ancient capital city of Elis, is the chief cattle market of the Peloponnesus. Thus closely does the prosaic present link itself with the heroic past. Thus persistently operate the geographic factors in history.

The highland core of the Peloponnesus, the plateau of Arcadia, contained several small lake basins with katavothra drains, subject to flooding after winter rains and spring thaw of the snow on the surrounding mountains. These afforded fine meadows, as the central pool contracted with the continued drought of summer, leaving a girdle of verdure behind. The lake plain of Orchomenus was mostly mere,[134] owing to the drainage from the surrounding heights; on the plain of Pheneus, according to tradition, Odysseus kept his mares on pasture.[135] All Arcadia became famous for its sheep, asses, horses and cattle.[136] Rugged mountain relief excluded horses and cattle from the small islands of Greece, but admitted sheep, goats and swine, where the forest yielded mast. Telemachus describes his native Ithaca as having "no open runs, no meadows, a land for goats and pleasanter than grazing country. Not one of the islands is a place to drive a horse, none has good meadows of all that rest upon the sea."[137] Therefore Odysseus pastured his goats and some of his swine on the home island,

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129 Theocritus, Idyls, XXV.
130 Iliad, XXIII, 202–203.
131 Iliad, XI, 671–680.
132 Iliad, XI, 707–723, 739–747.
133 Polybius, IV, 75.
134 Pausanius, VIII, ch. XIV, 1–4.
135 Ibid. VIII, ch. XIV, 5–6.
136 Varro, II, ch. I, 14; ch. IV, 12; ch. VI, 2; ch. VIII, 3.
137 Odyssey, IV 604–608; XIII, 241–246.

but sent his twelve herds of cattle and his flocks of sheep to pasture on the broad alluvial lowlands of Acarnania and Aetolia on the opposite mainland.[138] An Ithacan nobleman kept a stud-farm of twelve mares across the strait in Elis, where he bred mules.[139]

Stock-raising in Epirus.—Farther north on this western front of Greece lay Epirus, with high lake plains tucked away between its wooded mountain slopes, receiving 40 inches of rain (1,000 mm.) or more annually and getting thunder storms till mid-summer. Though located on the sunset side of Greece, far from the morning foci of Hellenic culture, the fame of its pastures and herds penetrated eastward, because it contained the Pelasgian sanctuary of Dodona. So Hesiod sang: "There is a land Ellopia with much glebe and rich meadows, abounding in flocks and shambling kine. There dwell men who have many sheep and many oxen. . . . And there upon its border is built a city Dodona."[140] The sanctuary lay on the southern margin of the katavothra pool, Lake Ioanina, which in ancient as in modern times was bordered by wet meadows, while the whole valley of Ioanina, 20 by 7 miles in extent, was one immense plain of pasture,[141] free from the encroachments of a too dense population. The cattle of Epirus were the finest of Greece, better than those of Italy, and therefore they were exported to improve the strains on Roman farms.[142] Aristotle states that Epirus raised very large cows which gave one and one-half amphora or ten gallons of milk daily; and that these cows, which required much pasture, could be changed to fresh grazing every hour, so abundant and excellent was the meadow land.[143] The oxen too were very large. Epirus pastured also the King's herds of huge Pyrrhic cattle which could not live, or more probably deteriorated, when removed to other countries.[144] Today the pasture lands of Epirus, still excellent and much extended by deforestation, support a considerable cattle and horse-raising industry.[145]

Sheep and Goats in Greece.—Goats and sheep were regular adjuncts of ancient Greek farms like the homestead of Odysseus; but in summer they went to "the high meadows of the pasturing flocks."[146]

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[138] Odyssey, XIV, 13, 99–103. Strabo, VIII, ch. VIII, 1.

[139] Odyssey, IV, 634–635.

[140] Hesiod, Catalogue of Women and Eoiae, 97. Loeb Lib., London, 1914.

[141] W. Leake, Northern Greece, vol. IV, pp. 131–135, 168–173, 184–200. London, 1835.

[142] Varro, II, ch. V, 10. Strabo, VII, ch. VII, 5, 12.

[143] Aristotle, *De Animalibus*, III, ch. XXI.

[144] Aristotle, *De Animalibus*, VIII, 7.

[145] Philippson, *Thessalien und Epirus*, p. 279. Berlin.

[146] Sophocles, *Edipus Rex*, 1103.

The shepherd in Sophocles' *Œdipus Rex,* when asked where he dwelt, replied: "Now t'was Kithaeron, now on neighboring heights." And again: "He needs must know when on Kithaeron's fields, he with a double flock and I with one, I was his neighbor during three half-years, from spring until Arcturus rose; and I in winter to my own fold drove down my flocks, and he to those of Laios" (in Thebes).[147] These mountain pastures were inter-state boundary zones, where shepherds and flocks from the two sides mingled every season. Here it was easy to spirit away a child across the border to an asylum in some shepherd's cot beyond, as was done with the infant Œdipus, rather than incur the moral responsibility of exposing him to the wolves.

The breeds of sheep and goats were selected for the improvement of the wool and hair. Cattle rearing too was conducted in Greece on scientific principles. Choice animals were reserved for breeding purposes, and the strain was improved by the importation of superior foreign kinds.[148] Aristotle states that the oxen and sheep of Greece were smaller than those of Egypt, though he seems to make an exception of the Epirote cattle.[149] In this connection, the fact is significant that Xerxes found the Thessalian horses, which were the best of all Greece, distinctly inferior to the Persian animals.[150] This may mean that horse-raising in Greece suffered from small numbers and excessive in-breeding, which frequently results in dwarfing; while the stud-farms of Babylonia comprised enormous numbers of animals. The cob type of horse depicted in the frieze of the Parthenon may be the far-off artistic effect of a geographic cause.

Mountain Pastures in Italy.—The location of Italy farther west and north than the lands of the Eastern Mediterranean Basin insured the peninsula a heavier rainfall and therefore better grazing.[151] Its relatively extensive coastal lowlands and river plains afforded larger areas for wet meadows than were found farther east, except in Egypt. The Alps, with their frequent summer showers and extensive growths of deciduous trees, furnished excellent highland pastures in the hot season. The Apennines, owing to their ample precipitation (35 to 50 inches), their long western slope facing the rain-bearing winds, and the top dressing of volcanic soil covering much of their valley floors, yielded fair or even excellent grazing for horses and cattle

147 Ibid, 1127, 1135–1139.
148 Blümner, Home Life of the Ancient Greeks, p. 497. London, 1895.
149 Aristotle, *De Animalibus,* VIII, ch. XXVII, 5.
150 Herodotus, VII, 196.
151 Strabo, III, ch. V, 1.

during the summer droughts, and thus supplemented the winter pastures on the plains. Geographic conditions in Italy therefore favored the development in ancient times of organized pastoral husbandry on a big scale, many phases of which have persisted to the present, despite the deterioration of the Apennine pastures in consequence of forest denudation. Before the Punic Wars, as now, flocks and herds were driven every spring from the plains of Apulia to the public grazing grounds in the mountains of Samnium;[152] and in autumn they descended again to the lowlands, to feed upon the meadows, reviving with the fall rains, or upon the stubble of the grain fields. In these seasonal migrations through the centuries they beat out broad, grassy tracks, the ancient *calles publicae,* which survive in the modern *tratturi* used today by the nomad herders.

During the last two centuries of the Roman Republic, stock-raising on big hill or mountain estates (*saltus*), varying in size from 800 to many thousand *jugera* (500 acres up) began greatly to overshadow tillage.[153] The term *saltus* came to be applied indifferently to a highland pasture and a mountain range or *massif,*[154] like the *Saltus Cminius* of Etruria and the *Saltus Vescinus* on the border between Latium and Campania. The animals raised were chiefly sheep, goats, and swine; in a less degree cattle, horses, mules, and asses, for whom suitable pasturage was in general less abundant.[155] However, the brushwood and leafage of the hill pastures, where groves of deciduous trees abounded, made a welcome and wholesome change to horses and cattle from the grass of the lowlands, and constituted one advantage of the transfer from the winter grazing land.[156] Another factor in the improvement may have been the escape from the mosquitoes and flies of the plains.

Cattle, horses, and mules of inferior breeds were raised in the Ligurian Apennines, where a rainfall of 50 inches (1,250 mm.) insured unfailing pastures, and were sold in Genoa whence they were exported to Rome.[157] In the extreme south of Italy, the high plateau-like range of Sila Mountain stretching through the length of Bruttium rises high enough (Sila Forest 6,330 feet and Aspromonte 6,420 feet) to get a rainfall rivalling that of the Alpine piedmont (43.3 inches

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152 Varro, II, ch. I, 16; ch. II, 9.

153 Mommsen, History of Rome, vol. III, p. 74. N. Y. 1905.

154 Catullus, XXXIV, 11.

155 E. Speck, *Handelsgeschichte des Altertums,* vol. II, part II, p. 240. Leipzig, 1901.

156 Varro, II, ch. II, 10.

157 Strabo, IV, ch. VI, 2.

at Cosenza).[158] It was therefore covered with forests and pastures, frequented by flocks and herds. "On mighty Sila feeds the lovely heifer," sang Vergil.[159] The cheese of the region was famous, "recalling by its taste the fragrant herbs on which the cattle browsed."[160] On the eastern slope of Sila Forest, in the valley of the Neaethus (modern Neto), Theocritus staged the meeting of neatherd and rustic in his fourth idyl. Today thousands of horses, cattle and sheep crop the summer herbage of the Sila pastures,[161] tended by rougher herdsmen than those who piped to the Greek Theocritus. Sicily presented a happy combination of upland pastures and moist, lowland meadows,[162] which made it a home of horse-breeders and cattlemen from early times. Horses and mules from Syracuse, Aetna, Acragas and Kamarina took prizes in the Sacred Games of Greece from 494 B. C.,[163] and cavalry forces were always at hand for the Tyrants of Syracuse.[164] The Roman conquest saw the whole interior of Sicily converted into vast grazing estates. The official plunder of the Proconsul Verres comprised "herds of the noblest mares."[165]

The Wet Pastures of Italy.—Italy had numerous wet pastures unreclaimed or unreclaimable for tillage, like the Fenland of England and the polders of Holland. The depressed area of northern Apulia, located between the Apennines and Monte Gargano, was a lake-strewn lowland of immature drainage underlain by hard limestone, which was impenetrable to the roots of trees.[166] Useless for orchard or vineyards, and flooded by the Apennine torrents from October to June, it served well for pasture land.[167] Greek legend associated the region with Diomedes, the great horse-fancier, and told of his attempts to control the inundations by cutting a canal through the lowland to the sea. The founding here of Argos Hippium or "horse-breeding Argos,"[168] which survived as the Roman town of Arpi, coupled with the legend of Diomedes, points to marsh pastures, which Greek colonists

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158 W. Deecke, Italy, pp. 82, 428–431. London, 1904.
159 Vergil, Georgics, III, 219.
160 *Cassiodori Variae*, II, 9–13.
161 Gael-Fells, *Unter-Italien*, p. 721.
162 Theocritus, Idyls, *passim*. Strabo, VI, ch. II, 3.
163 Pindar, Odes, Olym. I, III-VI. Pyth, I, II, III, VI. Diodorus Siculus, VIII, 82.
164 Thucydides, VI, 20.
165 Strabo, VI, ch. II, 6, 7. Cicero, Verres, II, 7, 20.
166 Deecke, Italy, p. 401. London, 1904.
167 Columella, VI, ch. XXVII, 2. Pliny, VIII, 154.
168 Strabo, VI, ch. III, 9.

exploited and drained by ditches during the winter floods. Here arose the Apulian breed of horses,[169] which was famous among the Romans.

Similar geographic causes and economic effects existed in the extensive marshes about the head of the Adriatic, which in summer afforded wide stretches of wet meadows. There the flood season was protracted long after the winter rains, owing to the slow melting of the Alpine snows; and there in a region of marshes, lagoons, braided streams, meandering rivers and deltaic distributaries, lived the ancient Veneti, from remote times famous for their horses. They let their equine herds pasture at large on the wet meadows, but branded each animal with its owner's name. Certain fine breeds of horses became established, and acquired a reputation even in Greece. The grazing was so excellent, that Dionysius, Tyrant of Syracuse, (d. 367 B. C.) kept his stud of race horses on these Venetian plains.[170] Similar conditions obtained over much of the level, well watered Po valley, where abundant irrigating streams, high water table, and occasional summer showers combined to keep the meadows green. There, on his father's Mantuan farm, Vergil knew the "wide pastures by the brimming river, where moss abounds and green herbage lines the banks;" and where brood mares and cows found the best grazing. There was the grass, the willow leaves, the marsh sedge and the standing grain which made the best fodder for growing oxen.[171] Countless irrigation streams, fed by Alpine rivers, kept the lush grass green throughout the hot season, and maintained the herds of cattle and the famous cheese industry of antiquity, much as they do today.

Wet meadows on a smaller scale were found in many longitudinal valleys of the Apennines, where the drainage was imperfect. Horace, on his frequent journeys to his Sabine farm up in the Anio valley, must have often seen these "grassy meads with winding streams and willows of the marsh."[172] He had one on his own estate which needed diking, because the winter or spring floods were sometimes excessive.[173] The Sabine country comprised also the Reate district with its excellent pastures, where Varro located his stud farm and where the famous Rosea breed of horses originated.[174] It lay in an old lake basin in the Sabine country, just where converging streams debouched upon the intermontane plain. Constant deposition of travertine, by the River Velinus, whose waters were impregnated with carbonate of lime, tended to dam the outflow, kept the valley floor too wet for tillage, and

169 Varro, II, ch. VII, 1. Columella, VI, ch. XXVII, 2.
170 Strabo, V, ch. I, 4, 5, 6.
171 Vergil, Georgics, III, 143–144, 175–176.
172 Horace, Odes, Bk. II, V, 1.
173 Horace, Epistles, Bk. II, XIV, 29.
174 Varro, II ch. VI, 1–2; ch. VII, 6; ch. VIII, 3.

finally flooded the Rosea pastures.[175] This necessitated a series of drainage canals, constructed through the centuries from 271 B. C., which reclaimed the Rosea plain for grazing.[176] In summer, the mules and asses of Reate were driven up into the neighboring mountains,[177] probably to release the Rosea meadows for hay crops. Similar valleys of immature or arrested drainage in Etruria and Umbria, like the lake-strewn course of the Clanis River and swampy course of the lower Arno in Etruria, must have provided the excellent meadows which, supplemented by the Apennine pastures, explain the good cattle and sheep, and the famous cheese of these districts.

Irrigated Fodder Crops in Italy.—The out-pastures of the mountains and marshes were abundantly supplemented by hay, clover, alfalfa and other fodder crops, maintained by irrigation through the summer, for the winter keep of the stock, especially the horses and work animals. Meadows were located preferably in rich valley or plain land. The soil, whether light and loose or stiff and heavy, was carefully tilled and regularly manured, especially on hillside fields. Marshy land, if in meadow, was drained by ditches and then irrigated at will.[178] Pliny urged that rain water from public highways should be diverted to the meadows, evidently because it contained soluble manure from the droppings of passing animals. Hay and clover fields were mowed in early June, irrigated, mowed again in August, and usually again in September or October. At Interamna in Umbria the farmers got four crops of hay a year,[179] as might be expected from the location of the place on a flood-plain peninsula between two streams. Lucerne or alfalfa fields regularly yielded six crops.

Even with this careful provision for fodder, animals were most economically fed. Cato recommended that the green leaves of elm, poplar, fig and oak trees, so long as they were available, should be fed to cattle and sheep, if hay were scarce;[180] that the straw of all grains, also of beans, vetch and lupines should be stacked in the barn for fodder, and grape husks preserved in jars for the same purpose; that mast gathered in the forests be soaked in water and fed to the oxen.[181] Chaff also, preferably that of millet or barley, was used as

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175 Deecke, Italy, p. 102. London, 1904.

176 Mommsen, History of Rome, vol. II, p. 85. N. Y. 1905.

177 Varro, II, ch. VIII, 5.

178 Cato, *De Re Rustica*, VIII, XXVIII, LIII. Columella, II, ch. 2, 17, 18. Varro, I, 29.

179 Pliny, VIII, ch. 28, 67. Varro, I, 31, 33.

180 Cato, *De Re Rustica*, V, XXV. Pliny, VIII, 74.

181 Cato, *De Re Rustica*, XXX, LIV.

feed.[182] Moreover the allowance of oxen for tillage land was small, only one yoke for every 80 or 100 jugera,[183] despite the numerous ploughings both of fallow and crop fields.

Cattle raising was an important branch of stock farming in Italy, because cows or oxen yielded various products (meat, milk, hides and horns) and served as the chief work animals. Horses and mules were extensively used as draft animals, more than in Greece and Asia Minor; because land travel was better developed in Italy, luxury had reached a higher point,[184] and the supply of animals was greater, owing to more abundant pasturage. Nevertheless, the effect of the summer drought in restricting the supply of horses remained apparent. From 200 to 50 B. C. the export of horses from Italy was forbidden by law. Certain Gallic envoys from Istria and the neighboring Alps in 170 B. C. received special permits to export ten horses each,[185]—proof of the rigid control. The importance of the unfailing northern pastures for horse-raising is evidenced by a fact cited by Mommsen, namely, that in the Imperial Roman army the cavalry was Celtic, recruited pre-eminently from Trans-Alpine Gaul, with Gallic men, whose manœuvers and technical terms were Celtic.[186]

Swine in Italy.—Swine production, which in the ancient Mediterranean world depended chiefly on mast-yielding forests, flourished in Italy, because climatic conditions permitted beech, oak and chestnut groves in nearly all parts of the peninsula. Pigs were raised on every landed estate.[187] They were fed mainly on the mast of the home woodland or the mountain forests,[188] and then fattened on barley and other grains to give the meat various flavors.[189] Beechnut bacon was a commonplace in Rome. No other country slaughtered so many pigs, for sacrifices, family use and the army commissary, according to Polybius. The chief supplies in his time (150 B. C.) came from the Po valley, whose northern location and encircling mountains ensured the late spring and early summer rains necessary to maintain abundant mast forests.[190] With the expansion of Roman power into Farther Gaul and the growing demand of the populace for imported food supplies,

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182 Pliny, XVIII, 72, 74.

183 Cato, R. R. X. Varro, I, ch. XIX, 1.

184 Blümner, *Römische Privataltertümer*, pp. 460–465. Munich, 1911.

185 E. Speck, *Handelsgeschichte des Altertums*, vol. III, part II, p, 284. Leipzig, 1901. Livy, XLIII, 5.

186 Mommsen, Provinces of the Roman Empire, vol. I, p. 116. N. Y. 1887.

187 Cicero, *De Senectute*, XVI, 56. Columella, XVII, 9.

188 Vergil, Georgic, II, 72, 520.

189 Varro, II, ch. IV, 3. Pliny, VIII, 209.

190 Varro, II, ch. IV, 10–11. Polybius, II, 15. Strabo, V, ch. I, 12.

this well forested northern province began shipping salt pork not only to Rome but to other parts of Italy. That from the Sequanian country at the head of the Saône valley had a great reputation.[191] The wooded slopes of the Pyrenees and rainy Cantabrian mountains of northern Spain also supported herds of swine, which furnished the basis for a lucrative native export trade in hams.[192]

Sheep in Italy.—Sheep-raising was widely distributed in ancient Italy, and it was semi-nomadic in its character, the flocks vibrating between the plains in winter and the Alps and Apennines in summer. The sheep producing the choicest wool, both as to softness, fineness and natural colors (white, black and tan), grazed on the leeward slopes of the Alps and Apennines, where the pastures were relatively dry. They were found in the south in ancient Apulia about Luceria and Canusium, in Calabria about Tarentum and Brundusium, in eastern Lucania and the nearby valleys of the Sybaris and Crathis.[193] Their superiority in this district may be attributed in part to the fact that they belonged to the fine Greek breeds imported by the original colonists of Magna Graecia.[194] In northern Italy also the finest fleeces came from the rain-shadow sides of the Apennines and Alps; from the *Campi Macri* in the northern Apennines between Parma and Mutina, whose fine toga wool ranked with that of Tarentum;[195] from western Liguria at the eastern foot of the Alps about Pollentia; and from the Venetian plain about Altinum, whose product ranked next to that of Apulia and Parma.[196] All the Po valley pastures produced coarse wool and goats' hair suitable for weaving rough cloth for mantles and slaves' dress. The finer yields were evidently a late development,[197] synchronous with the advance of civilization and movement of population into this colonial frontier district of Roman Italy. Significantly enough, all these regions of fine wool production have maintained their leadership into the present.[198]

The Improvement of Breeds.—At a time when the rainy lands of middle and northern Europe knew only uncontrolled stock-raising on the open range, Italy, like Greece, secured the largest financial

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191 Strabo, IV, ch. I, 2; ch. III, 2; ch. IV, 3.

192 Strabo, III, ch. IV, 11.

193 Horace, *Carmina*, Bk. III, XV, 13. Columella, VII, ch. II, 3; ch. IV, 1. Pliny, VIII, 190.

194 Blümner, *Römische Privaltaltertumer*, p. 237. Munich, 1911.

195 Columella, VII, ch. II, 3. Strabo, V, 218.

196 Martial, XIV, 155.

197 Columella, VII, ch. II, 3.

198 L. W. Lyde, Continent of Europe, p. 94. London, 1913.

returns from its relatively limited pastures by improving its stock through artificial selection.[199] It laid great emphasis upon the choice of the best strains for breeding purposes. Horned cattle were imported from the Po valley and Epirus to improve the local breeds,[200] especially large cows from the Pyrrhic herds, which had a great reputation in Italy.[201] The Italian cattle, which were bred primarily for work animals, were strong but gave little milk. Hence it became usual to import good milk cows from the Alpine regions.[202] Significantly enough, the same thing is done today on a big scale to exploit the wet meadows along the Po River, which are devoted to dairy cattle. Swiss cows are imported since they yield more milk when fed on these irrigated pastures for ten months than do the native Italian kine,—700 as opposed to 550 gallons. This large milk production explains the modern trade in Parmesan, Gorganzola and Stracchino cheese which emanates from this region.[203] In ancient times the Apennines of Umbria, Etruria and Liguria were the chief districts of cheese production,[204] but the Alpine cheese of Narbonensian Gaul was the best, according to Martial.[205]

But the improvement of stock was not restricted to cattle. Fine mares of racing blood were imported from Thrace, Thessaly and Epirus,[206] asses for breeding purposes from Arcadia,[207] fine sheep from Attica and other parts of Greece,[208] and rams for covering from the Guadalquiver valley of Spain.

Narbonensian Gaul formed a connecting link geographically and economically between Alpine Italy and Pyrenean Spain, owing to location, relief and climate. The valley plain and deltaic flats of the Rhone furnished moist pastures[209] till July, just as they do today,[210] while the neighboring Alps and Cevennes Plateau furnished summer grazing. The abundance of cattle about Massilia was reflected in the low price paid for sacrificial oxen and young bullocks in the fourth century B. C. at the local Carthaginian temple, whose tariff of charges

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199 Vergil, Georgic, III, 156–161.
200 Varro, II, ch. V, 9–10.
201 Pliny, VIII, 176.
202 Columella, VI, ch. XXIV, 5. Pliny, VIII, 179.
203 G. C. Chisolm, Commercial Geography, p. 337. London, 1904.
204 Pliny, XI, 97.
205 Martial, XIII, 30, 31.
206 Vergil, Georgic, I, 59; II, 90.
207 Varro, II, ch. VIII, 3. Columella, VII, 1.
208 Varro, II, ch. II, 18. Columella, IV, 1.
209 Strabo, IV, ch. I, 7.
210 E. Reclus, Europe, vol. II, pp. 99-102. N. Y. 1883. Also personal observation in 1922.

has been preserved;[211] and it explains the ancient cheese export from Nemausus (Nimes) and the district of the Gabali,[212] famous for its cheese today.

Stock-raising in Spain.—In the rainy mountains of northern Spain, swine raising and the pork-packing industry were supplemented in the rugged provinces of Asturia and Gallacia by the breeding of sumpter mules, which answered the local need of transportation and were also exported to Rome.[213] On the steppes of the semi-arid Iberian plateau, large herds of wild horses pastured at large. They were fine swift animals, and explain the superiority of the native Iberian cavalry.[214] Hannibal had large numbers of African horses in Spain in 219 B. C., and he invaded Italy with 12,000 cavalry, chiefly Numidian but partly Spanish. In time, the Spanish breeds were greatly improved, because Spanish race horses competed in the Roman Circus with Cappadocian, Parthian and Armenian steeds in the first century of the Empire. Martial praises the horse racing at Bilbilis, on the northeastern rim of the Meseta. The economy of the highland tribes was primitive, based chiefly on a half-migratory agriculture and goat-herding, which was suited to their dry grass lands. Cattle-raising as an adjunct of sedentary tillage meets us only in Baetica in the tide-water plains of southwestern Spain, where Phoenician colonists early established themselves. There, in a region of scant rainfall (12 to 15 inches), the belt of littoral between the multiple mouths of the Guadalquiver and the Guadiana afforded natural meadows, which were watered both by meandering distributaries and flood tides. Those near Cadiz seem to have been communal pastures, probably owned by the city. The cattle grazing there were fat and yielded rich milk, but they were occasionally overwhelmed by the incoming tides.[215] The dry pastures of the Guadalquiver valley supported excellent sheep, whose wool was famous in the Roman world for its softness and color, especially the reddish-tan wool of the Corduba (Cordova) district.[216] The folded mountain ranges which enclose this valley on the south received enough rain for extensive forests of oak and other trees. These apparently sup-

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[211] A. Boeckh, *Die Staatshaushaltung der Athener*, vol. I, p. 95.

[212] Pliny, XI, 97.

[213] E. Speck, *Handelsgeschichte des Altertums*, vol. III, part II, p. 283. Leipzig, 1901.

[214] Strabo, III, ch. IV, 15.

[215] Strabo, II, ch. II, 4, 5, 6; ch. V, 4.

[216] Blümner, *Römische Privataltertümer*, p. 240. Munich, 1911.

ported herds of swine, for Strabo tells us that Mellaria (modern Tarifa) produced salted provisions and exported them to Tingis (Tangier) in Mauretania.[217] These salted provisions undoubtedly comprised pork products, though they may have included also salt fish.[218] On the northwest side of the Iberian Peninsula, where exposure to the Atlantic winds insured unfailing rains, there was ample pasturage all year round, both in the plains of the Tagus and Duoro and on the neighboring highlands. This is indicated by the abundance and cheapness of oxen, calves, pigs and sheep in ancient Lusitania (Portugal),[219] where the grazing conditions resembled those of northern Italy.

Stock-raising in Mediterranean Africa.—North Africa reproduces the climatic conditions of interior Spain and the Guadalquiver valley, with their attendant effects upon stock-raising. In the territory of ancient Carthage, cattle and horses were associated with tillage in the irrigable plains near the coast. There in the moist alluvial valley of the Bagradas River (Majerda River) the invading army of the Sicilian Agathocles (4th Century B. C.) saw cows, oxen and sheep grazing in the irrigated meadows, while "in the near-by marshes there were vast numbers of brood-mares."[220] The interior grasslands, lying in the rain-shadow of the Atlas ranges, were pastured by big herds of horses and cattle belonging to the nomads of Numidia and Mauretania.[221] These supplied the Numidian cavalry which formed an important part of Hannibal's forces in the Second Punic War, and constituted the major part of Massinissa's army, Scipio's ally, in the Roman campaign in Africa.[222]

Farther east, on the Cyrenaican coast of Africa, the plateau of Barca (elevation 2,000 feet or 610 metres) was high enough to condense winter rains in this otherwise arid belt, and therefore to support good but ephemeral pastures for horses and cattle back to the margin of the desert.[223] Springs issuing from the escarpment and base of the limestone highland irrigated fields and hay meadows. Hence the Greek colony of Cyrenaica enjoyed a great reputation for horse

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[217] Strabo, III, ch. I, 8.
[218] Strabo, III, ch. II, 6.
[219] Polybius, XXXIV, 8.
[220] Diodorus Siculus, XX, ch. I, 8.
[221] Strabo, XVII, ch. III, 7, 9, 19. Mommsen, Provinces of the Roman Empire, vol. II, p. 368.
[222] Polybius, III, ch. 35, 65, 68, 71, 72, 113, 114, 117; XV, ch. 3, 5, *et passim*.
[223] Arrian, *Indica*, ch. 43.

breeding in antiquity.[224] Its kings frequently won the chariot races in the Greek Games and became the theme of many a Pindaric ode.[225] The colonists doubtless purchased horses from the neighboring nomads, whose route to the coast ran right past the city of Cyrene,[226] and then improved the animals by good feeding and training.

Pastoral Nomadism on the Arid Margins.—Horses and cattle, sheep and goats, formed the chief wealth of the nomads who hung on the semi-arid outskirts of the Mediterranean lands, and ranged widely in search of grass. Their animals drifted into the markets and stockfarms of the sedentary Mediterranean peoples in a dozen different ways,—by purchase at border trading-post or town, by capture during nomadic invasions or in the subsequent punitive expedition of the farmer nations, or by the employment of nomad cavalry as allies or mercenaries in war. This was especially the case with horses and cattle whose importation when full-grown worked an economic saving in countries of limited pasturage. As a corollary, this saving was greater, as a rule, in eastern Mediterranean lands than in western.

The sources from which such imports were drawn were not limited to the semi-arid regions to the south and east of the Mediterranean; they included the European steppes bordering the Black Sea and the well-watered districts north of the Alpine barrier. Cattle, hides and wool were regularly purchased by the ancient Greek traders from the Scythians of the Euxine coast,[227] and they were also imported into Italy from the upper Danubian plains by the passes of the Julian Alps and Carso Plateau.[228] Marine transportation of live animals presented no problem, as has been shown.

Thus the economic history of the Mediterranean lands can never ignore the factors of climate, relief, and the uniting force of the *Mare Internum*.

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[224] Strabo, XVIII, ch. III, 2.
[225] Pindar, Odes, Pyth, IV, V.
[226] E. Curtius, History of Greece, vol. I, pp. 486-487. N. Y. 1867.
[227] Ibid. vol. I, pp. 440–441.
[228] Strabo, V, ch. I, 8.

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THE VEGETATIONAL HISTORY OF THE MIDDLE WEST

HENRY ALLAN GLEASON

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Part I

The Dynamic Viewpoint.—Many years have elapsed since Engler published his famous and fundamental "Leitende Ideen," which he had adopted as a basis for his discussion[1] of the Tertiary and Pleistocene development of the vegetation of the earth. Here, in thirty-six concise paragraphs, he summarized the general principles controlling the distribution of species and of species-groups. The first two of them serve as a summary for all:

"1. Die gegenwärtige Verbreitung der Pflanzen ist nicht blos bedingt durch die jetzt auf der Erde herrschenden klimatischen Bedingungen und die Bodenverhältnisse.

"2. Ein wahres Verständniss der Verbreitung der Pflanzen ist nur dann möglich, wenn man die allmälige Entwicklung derselben zu ermitteln sucht."

Engler was apparently inspired to his studies of vegetational history and development, at least in part, by the classic essays of Asa Gray.[2,3,4] His lead was followed by numerous European botanists, who, assisted by the co-operation of palaeontologists and glacial geologists, have in the past two decades contributed greatly to the knowledge of the phytogeographical history of central and western Europe. Later American botanists, on the other hand, neglected such lines of investigation almost completely and their phytogeographical activities were confined, as is natural in relatively new regions, to descriptions of floras and the determination of modern distribution. It remained for Adams[5,6] to revive developmental biogeography in America and to show that the distribution of a species can be satisfactorily explained only through the location of its origin and the nature of its subsequent migrations.

General Control of Distribution.—The distribution of plants, as shown by Engler's principles quoted above, depends, in general terms, on modern environment and earlier developmental history. Both

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[1] Engler, Adolph. Versuch einer Entwicklungsgeschichte der Pflanzenwelt, insbesondere der Florengebiete, seit der Tertiärperiode. Leipzig, 1879.

[2] Gray, Asa. The flora of Japan. Scientific Papers 2: 125–141. (1859) 1889.

[3] Gray, Asa. Sequoia and its history. Scientific Papers 2: 142-173. (1872) 1889.

[4] Gray, Asa. Forest geography and archaeology. Scientific Papers 2: 204–233. (1878) 1889.

[5] Adams, C. C. Southeastern United States as a center of geographical distribution of flora and fauna. Biol. Bull. 3: 115–131. 1902.

[6] Adams, C. C. Postglacial origin and migrations of the life of the northeastern United States. Journ. of Geog. 1: 303–310, 352–357. 1902.

of these are intimately concerned with migration, the latter factor portraying its progress and the former its limitation. Neither factor alone can account completely and satisfactorily for the present range of any species. This is the resultant of its range at any period in the past and its opportunities for subsequent migration; one exposure in the long film of an activity which has been continued since the origin of the species. If logs in the glacial drift show that *Pinus Strobus* formerly existed in central Illinois and experiment proves that it can thrive there now, historical evidence must be used to show why it left: modern conditions may show whether and why it is not returning.

Vegetational History and Human History.—The history of the vegetation of the Middle West, as of every other portion of our continent, is a history of repeated migrations of diverse floristic elements, arriving in the region from various directions, persisting there for various lengths of time, and finally retreating under the pressure of environmental changes which made their position no longer tenable. This history has been complicated by the extinction of old and the differentiation of new species, by the mingling of species of originally different history, and by the persistence of isolated relics of early migrations. In all these respects, vegetational history exhibits a striking parallelism to human history. Thus Europe has witnessed during the last two millenniums the extinction or absorption of the early Iberians, the persistence of the Basques, the arrival and retreat of the Moors and Turks, and an enormous evolution in culture. Furthermore, the underlying causes of vegetational and human history are similar, even though the human species exhibits an exceedingly complex relation to its environment. The geography of man has long been recognized as merely the present condition of his history, and the relations of both to natural conditions and processes have been well summarized.[7] Unfortunately, no such summary exists for plants.

Outline.—It has therefore been necessary to preface this history of plant life in the Middle West, presented in Part IV., by a discussion of the conditions and nature of plant migrations in Part II., and by a resumé of the evidence used in determining past migrations in Part III.

Part II. The General Nature of Plant Migrations

A great body of literature dealing with the migration of plants has appeared in the last century and a half. This has been so well summarized by Clements[8] that it needs no further discussion here. Most

[7] Semple, Ellen C. Influences of geographic environment. New York, 1911.

[8] Clements, Frederic E. The development and structure of vegetation. Studies in the vegetation of the state III. Botanical Survey of Nebraska VII. Lincoln, 1904.

of it deals with the migration of individual species, and Clements' exposition of the whole subject is without doubt the best general treatment extant.

INVASION, MIGRATION, ECESIS.—Following Goeze, he considers the general movement of species or associations under the term *invasion,* and recognizes that this consists of two distinct processes. One of these, to which he restricts the term *migration,* involves merely the movement of the plant by means of its reproductive bodies or vegetative processes. The mechanics of such movement, the methods of seed dispersal or vegetative propagation, while exceedingly diverse, are already well understood and require no discussion here. The second process, which he terms *ecesis,* includes the actual establishment of the plant in a new location. Ecesis depends entirely upon the environmental conditions of the new location in their relation to the physiological requirements of the seedlings. The details of these relations are for most plants entirely and for all plants mostly unknown, and are to be determined by the methods of experimental ecology. Migration, in Clements' use of the term, is completely unsuccessful in the failure of ecesis, and ecesis, to be effective and complete the process of invasion, must be carried to the maturity of the plant and the production of a second generation of disseminules. The distinction between the two processes is fundamental, and Clements' clear analysis has done much to systematize the knowledge of the subject.

The term *invasion,* which Clements applies to the whole phenomenon of movement, is in many cases scarcely appropriate. His own definition and the general meaning of the word both imply a movement of plants into an area not before occupied by them, that is, an extension of their range. As a matter of fact, the migration of plants is almost or quite as frequently out of an area previously occupied as into a new one, and then involves a retreat or restriction of their range, a result to which the term invasion can not be properly applied. The term migration, in the sense of Clements, is distinctly a process of one generation. Ecesis involves the development of a second generation of individuals, but scarcely applies to the whole population of a species. Yet these processes, participated in by a whole population and continued regularly through successive generations, may lead to broad results far more inclusive than those chiefly considered by Clements. For the purposes of this article, the migration of plants is understood as any general movement by which the range of a species is changed.

EFFICIENCY OF PLANT DISPERSAL.—The efficiency of plant dispersal is well understood. Each normal individual produces one or many

crops of seeds or other reproductive bodies and these are dispersed thoroughly over the surrounding territory to an extent dependent upon their structure and their environment. At the margin of the present range of a species, whether that margin is the boundary of an association in which it occurs or the general margin of its whole range, seeds are annually dispersed in all directions, inward through its present range and outward and beyond it as well. Examples of this are well known and need not be cited. Except in comparatively infrequent cases, where the ability to produce seeds or other reproductive bodies is lost, the potentiality of continuous and extensive migration is constantly present. The slow rate of actual normal migration is not due to inefficiency of the migratory devices of the plant, nor, except as mentioned above, to deficient seed production, but to the inhibiting effect of environmental factors in the area beyond the present distribution of the species. This is particularly true toward the center of the range. Every swamp is annually and abundantly planted with seeds of upland species, while the swamp plants are simultaneously distributed over the upland, and in neither case do any of them grow, except under the most unusual circumstances.[9] Even at the margin of the specific range, where reduced or intermittent seed production might be expected, Griggs has shown that many species are able to propagate themselves freely.[10]

There is for each species a general limit of distance over which its seeds may be dispersed. The number of seeds arriving on any area diminishes with increasing distance from the parent plant; in fact, for small distances, the number seems to vary inversely as the square of the distance. Since only a small portion of the seeds germinate and grow to maturity, most young plants of the second generation are located relatively close to the parent.

Migration and Succession.—Actual migration, therefore, requires a change in the existing environment for its inception. (The abnormal type of migration, due to the acquisition of new means of dispersal by which previous environmental barriers are crossed, is mentioned in a later paragraph.) A migratory advance postulates the development of individuals in territory not previously occupied and requires an environmental change of sufficient extent not merely to permit the growth of the migrants, but to permit it against the competition of the previous inhabitants. A migratory retreat requires a detrimental

[9] Brewster, William. Occurrence of the skunk cabbage in an unusual place. Rhodora 11: 63, 64. 1909.

[10] Griggs, Robert F. Observations on the behavior of some species at the edges of their ranges. Bull. Torrey Club 41: 25–49. 1914.

change, either in physical conditions or in their control by plant life or in parasites and enemies, sufficient to prevent the establishment of new plants in the immediate vicinity of the parent, so that the species disappears from the habitat with the death of existing individuals. Succession results when migration is so complete and is shared by individuals of so many species that the nature of the vegetation is fundamentally changed. The close relation between succession and migration have been noted elsewhere,[11] and the nature of the causal environmental changes have been discussed in detail by Clements.[12] Instances are of course well known in which species migrate into an association and become an integral part of it without causing succession. Thus in parts of New Jersey *Daucus Carota* has entered the hemlock-maple forest, and in northern Michigan *Rumex Acetosella* has become widely distributed through the aspen association. Such a result may be termed taxonomic succession, as distinguished from the ecologic succession previously mentioned.

Rate of Migration.—The simple production, movement, and establishment of reproductive bodies, constituting together the method of migration, is not the only factor concerned in the process. The rate of migration depends upon one or the other of two conditions: the rate of environmental change and the migration-capacity of the plant. The latter condition may in turn be resolved into two components; the mobility of the plant, depending on the structure of its migrating parts and its ability to utilize the necessary environmental agencies, and the length of its juvenile period, which must be completed before a new crop of disseminules is produced to continue the march. Migration-capacity may be formulated in general terms as mobility divided by length of juvenile period. Hence those plants which combine excellent structural devices for dispersal with a short vegetative cycle, such as the dandelion (*Taraxacum*), migrate more rapidly than others with less mobility, as lamb's-quarters (*Chenopodium*), or with a long vegetative period, as the maple (*Acer*), while slowest of all are those plants which lack both favoring features, as the oak (*Quercus*). The actual rate of migration is fixed by the slowest of the two general conditions. If environmental change is slow, migrating species may keep even with it and continually scatter their seeds forward into territory where they can not yet grow. If environmental change is rapid, the slower species may not be able to keep even with it and consequently follow

[11] Gleason, H. A. The structure and development of the plant association. Bull. Torrey Club 44: 463–481. 1917.

[12] Clements, Frederic E. Plant succession, an analysis of the development of vegetation. Carnegie Inst. Washington, Publ. 242. 1916.

at a distance far behind other more mobile forms. Thus in the slow extinction of a pond by the deposition of peat, there is no break in the time-continuity of the contracting zones of vegetation around it, since mobility exceeds the rate of environmental change. But if a pond is drained artificially, producing in a single year an effect similar to that of a century of peat formation, the more mobile species enter first on the freshly exposed area and some years may elapse before all the remainder have appeared. So also the sudden cessation of prairie fires on parts of the prairies led to the immediate advance of the forest, and the more mobile species composed the bulk of the early invaders. In general, migration connected with physiographic succession keeps pace with the environmental changes, so that associations are well marked and the correlation between zonation and succession is prominent. Even such a slow environmental change as the advance or retreat of a continental glacier may have been too rapid for some species, while certainly slow enough for others. Numerous species were doubtless destroyed completely with the advance of the glaciers and others during their retreat, from inability to keep pace in their migration with the changing conditions of the environment.

The most rapid rate of migration is found in the anthropochorous species which utilize human activities for their dispersal. Such not only move with extreme rapidity, but by the nature of their dispersal are able to cross barriers quite impassable for other species. Our own country has been occupied during the past century by hundreds of such species which have crossed an ocean to reach us and have spread hundreds of miles over the land in a very short time. Yet most of these same species are stopped completely by an area of undisturbed natural vegetation, which they are unable to colonize.[13]

The Time Factor and Migration.—The present status of migration depends upon its rate, as discussed in the preceding paragraph, and on the elapsed time since migration began. The more rapidly moving species may be at the limit of their present potential range and wait upon further environmental change, while the slower ones may be far from their actual limit, although progressing toward it at their best speed. The condition is well illustrated in the belts of forest which parallel the rivers of Kansas and Nebraska, in which, in general, the more mobile species have extended farthest to the west.[14] It is also prominent throughout the prairie region of the Middle West, where

[13] Gleason, H. A. & F. T. McFarland. The introduced vegetation of the vicinity of Douglas Lake, Michigan. Bull. Torrey Club 41: 511–521. 1914.

[14] Kellogg, R. S. Forest belts of western Kansas and Nebraska. U. S. Dep. Agr. Forest Bull. No. 66. 1905.

there is a continuous movement of the more mobile forest species into the land originally occupied by prairies.

The time factor naturally begins with the origin of the species concerned. Those of relatively recent origin have had little time in which either to extend or to contract their original ranges. Since major environmental changes are usually slow in their accomplishment, recent species have in general had also relatively little opportunity to use their migratory abilities. Such species are therefore restricted more closely to the site of their origin.

It is probably true, however, that many of our species have not had a single point or even a limited area of origin. The bulk of later Tertiary plants, as far as palaeontological evidence indicates, are of genera still existing, and many of the comparatively few known species of Pleistocene plants are either identical with or closely similar to existing species. Such evidence deals especially with woody plants, but what is true of them is doubtless true of herbaceous plants as well. The distinction between such Pleistocene plants and their modern representatives may depend largely on a break in the record, on a period from which fossils are lacking. Probably if a complete series of specimens were at hand, showing comprehensively the maples of the eastern states, for example, from the Pliocene to the present time, it would be seen that some of the earlier forms are absolutely continuous with our present species and that the slight morphological distinctions between them are only the result of continuous slow variation throughout the centuries. According to this view, many modern species had no localized origin and are not the offshoot of any parent, but represent the mass development of a species, which, under our present taxonomic ideas, came to a stop at the beginning of a break in our geological record of it and reappeared as a new species at the beginning of our next experience with it. During the long history of such a species, most of which is unknown to us, it may have migrated repeatedly in various directions, occupied larger or smaller areas, been separated into disjunct regions and again united, or one part of its population exterminated, and its range as we see it today represents merely the present condition of this long development. We are never sure of the prehistoric stages in this history, through the imperfections in the fossil record, but in certain cases we can arrive at some idea about them by circumstantial evidence.

Such a consideration does not account for the multiplication of species. Whether that is caused by mutation, natural selection, or hybridization, it seems certain that their perpetuation to the present time has depended greatly upon their ability to migrate as changes of environment demanded.

SIGNIFICANCE OF THE MARGIN OF RANGE.—The margin of the range of a species, then, does not always represent the boundary of the territory in which the species can or will live under present conditions, but merely the distance which it has travelled so far in its march to this goal. Instances are not lacking, of course, in which this migration has been completed and further extensions or retractions of the range wait upon future climatic changes. As one illustration, the distribution of *Pinus ponderosa* along the eastern foothills of the Rocky Mountains may be cited, where it has been clearly shown[15] that the species is now at the margin of its potential range. On a smaller scale, a sharply marked boundary between two associations indicates completed migration in that restricted area of the species on both sides of the boundary to the limits permitted by the present environment.

ADVANCING AND RETREATING MIGRATIONS IN THE MIDDLE WEST.—Both advancing and retreating migrations are now in progress in the states of the Middle West. In most cases these movements are too slow to come under direct observation, and reported extensions of ranges are generally due to incomplete or faulty early observations. Still the rapid spread northward of *Prosopis glandulosa* from Texas across Oklahoma into Kansas,[16] the westward migration of trees along the rivers of Nebraska,[14,17] and the recent discovery of young trees of *Quercus palustris* in southeastern Nebraska[18] may be cited as instances of visible migration. In general, migration is shown chiefly by the rôle of the species in succession. If, at or near the edge of its range, it participates in succession as an invading species, it is advancing; if it is not able to hold its own in competition, if the associations of which it is a member are regularly succeeded by others of which it is not a part, a retreating migration is indicated. This is illustrated in Michigan and Wisconsin by the regular succession of coniferous associations by deciduous forests, indicating the retreat of the conifers and the advance of the deciduous trees.[19]

EFFECTS OF CHANGES IN PHYSIOLOGICAL REQUIREMENTS.—There is no reason why changes in the physiological requirements of a species

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[15] Dodds, Gideon S., Francis Ramaley, & W. W. Robbins. Studies in mesa and foothill vegetation, I. Univ. Colorado Studies 6: no. 1, 11–49. 1908.

[16] Bray, William L. Distribution and adaptation of the vegetation of Texas. Bull. Univ. Texas 82. 1906.

[17] Bessey, C. E. Are the trees advancing or retreating upon the Nebraska plains? Science II., 10: 768-770. 1899.

[18] Pool, Raymond J. Pin oak in Nebraska. Torreya 20: 50-52, 1920.

[19] Whitford, H. N. The genetic development of the forests of northern Michigan: a study in physiographic ecology. Bot. Gaz. 31: 289–325. 1901.

might not have the same effect as a change of environment in causing migration. It is well known that plant breeders have developed new races of cultivated plants which thrive in climates different from that of the original home of the species. Possibly the rapid spread of American Opuntias in parts of Australia may be explained in this way. Under natural conditions, such changes in physiological requirements are usually correlated with changes in structure, and the latter are used as a basis for taxonomic differentiation. Whenever such evolutionary changes appear, new areas may be opened to the new species and eventually occupied by them. So such genera as *Eupatorium* and *Vernonia,* originating probably in northern South America, have migrated northward into the cold-temperate zone, as evolution has changed their physiological requirements and morphological structure. So have bromeliads migrated away from the humid tropical forests, entered the deserts of southern Mexico, and established themselves as epiphytes on the cacti;[20] so have the cacti migrated out of the desert region, where they probably originated, and established themselves as epiphytes in the tropical forest.

Migrations as Related to Continuity of Suitable Habitats.—The range of every species is discontinuous. Throughout its whole area only particular habitats are occupied, leaving others to different species and associations. In each habitat, the space is shared with other associated species. These phenomena are in general of ecological rather than geographical interest, but are still of importance in their relation to the direction of migration. Within the habitat, so far as the association is continuous, even the least mobile species may migrate freely and ultimately attain a uniform distribution.[11] But from one habitat to another, the means of dispersal must be sufficient to carry the species across the intervening gap, which becomes a barrier to the less mobile forms. During the long course of time, accidents of dispersal may carry many species across a barrier, but accidents are probably not as efficient as frequently supposed. Mink Grove and Lynn Grove, two isolated areas of forest in Champaign County, Illinois, had large trees in them when first observed by white men nearly a century ago, and their age is doubtless 150 years at a minimum. Although these groves lie but a few miles from the nearest strips of forest along streams, in which species of *Hicoria* and *Quercus* are abundant, not an individual of these genera has reached them. Extensive migrations of plants, proceeding at a relatively rapid rate, therefore take

[20] MacDougal, D. T. Botanical features of North American deserts. Carnegie Inst. Washington, Publ. 99. 1908.

place along routes where suitable habitats are nearly continuous, such as river valleys for mesophytic species or interfluvial uplands for xerophytic forms. There is every reason to believe that the postglacial migration of the deciduous forests into the Middle West followed the river courses almost exclusively. From these earlier migrations along the line of least resistance, a slower type of migration gradually extends the range out upon other habitats. This follows regularly the physiographic development of an area, as Cowles has shown,[21] and may also be induced by the reaction of an association upon the environment in the margin of a contiguous association beyond it.[11] So the forests of the Middle West, entering the region along the nearly continuous habitats of the river courses, where they migrate rapidly, have also spread at right angles to them, but more slowly, until in some cases those of different river systems have become united.

Each important change in the climate or the configuration of the land, due to geological causes, has created new migration routes and destroyed old ones, interrupting migrations then in process and initiating new ones, which may progress in different directions and be participated in by plants of different origin. There is evidence of several such migrations in the Middle West, which are discussed in Part IV.

The Interpretation of Isolation.—Actual geographical isolation of a species, in the ordinary sense, is effective only when an outlying habitat is separated from the general range by a distance greater than the migration-capacity of the plant. Instances of this are too well known to need citation. Only two explanations are possible for such a condition. Either the species has had two separate and independent origins, or else the vicissitudes of migration have brought it about. Even if the possibility of the former alternative is admitted, the latter is the more plausible in the majority of cases. It implies that the two disjunct bodies of the species were at some time one, either in a territory from which both portions have migrated and which is no longer occupied, or through the existence of connecting links between the two which have now disappeared. Both cases have been caused by a retreating migration.

Environmental changes which permit the advance or compel the retreat of one species are quite likely to affect others similarly, since associated species demand in general the same environment. Migration is therefore concerned with numerous species simultaneously.

[21] Cowles, H. C. The physiographic ecology of Chicago and vicinity; a study of the origin, development, and classification of plant societies. Bot. Gaz. 31: 73–108, 145–182. 1901.

Whole floras migrate together, the hardiest and most mobile species first, the others in their train. They establish successional series in the region which they enter, and build up new associations in the new territory. These are analogous to the associations of their original range, but differ in the absence of the slower moving species and in the presence of laggards from the retreating flora.

Just as portions of a single species may be isolated during its migrations, so may areas of one type of vegetation be completely surrounded by an advancing flora and left isolated from the main body. These are known as relic colonies. The cause of such isolation is the failure, up to the present time, of sufficient environmental change to cause their extinction, or, in ecological terms, it is the relative slowness of the succession in certain habitats unfavorable to most of the advancing species. These habitats remain with their original vegetation upon them, while elsewhere it is displaced. Such relic colonies are of common occurrence wherever migrations are recent. Every movement of vegetation has certainly left relic colonies behind it, but their perpetuation to the present time depends absolutely on the continuation of an environment not only favorable to the relic species but distinctly unfavorable to the invaders.

Adjustments in Distribution.—The distribution of a species and the distribution of vegetation must both be regarded as subject to continual adjustment. Boundaries extend and contract, associations advance and retreat with every geographical fluctuation of the environment. Even within the limit of a single association, every minor environmental variation, whether geographical or seasonal, is marked by the entrance or disappearance of some species, or by changes in the numerical proportion of the others. This may account for the conditions recently reported on Mt. Marcy,[22] where twenty-one species formerly reported by Peck have apparently disappeared and seven "rather conspicuous plants, which such a careful botanist could scarcely have missed, have apparently come into the flora."

General Results of Continued Migrations.—Obviously the general result of continued migrations is the mingling of floras of diverse origin, while great climatic changes or important geological episodes tend toward the segregation of floras and the consequent initiation of new migrations. Regions affected by Pleistocene glacia-

[22] Adams, C. C., Geo. P. Burns, T. L. Hankinson, Barrington Moore, & Norman Taylor. Plants and animals of Mount Marcy, New York. Ecology 1: 71-94, 204–233, 274–288. 1920.

tion, such as the area here discussed, fall in this group, and in them floras of different origin are still relatively distinct and adjustments of range are actively in progress. On the other hand, in regions which have enjoyed relatively uniform environmental conditions for a long period of time, migrations are more generally completed and vegetation is in more nearly a static condition, except in those successional series which are related to continuous physiographic processes such as baseleveling. This is now the case in parts of the tropics, and was formerly the case over wide areas of the North Temperate zone in the later Cretaceous and earlier Tertiary periods, when the flora and vegetation of North America and Eurasia were remarkably uniform.

Summary of Part II.—1. Migration of a species depends on an environmental change within or beyond its range.

2. The rate of migration depends on the rate of environmental change or the migration-capacity of the plant.

3. The present status of migration, as shown by the range of the species, depends on its rate and on the time available for it.

4. The present range of a species is not necessarily final, even without further environmental change.

5. Migration proceeds most rapidly along routes with nearly continuous habitats.

6. Species of similar environmental demands migrate together.

7. Isolated areas of a species or of vegetation are to be interpreted as results of retreating migration.

8. Long continued uniformity of environment leads to floristic uniformity; recent environmental changes to floristic segregation and to new migrations.

Part III. The Evidence of Plant Migrations

The entire distance which may have been travelled by the native plants of the Middle West in their migrations since the close of the last glaciation seldom exceeds 500 miles. Since the time available for this movement may be 10,000 to 40,000 years, this requires an average annual migration of only 66 to 264 feet. In the case of trees, a juvenile period of 20 years would still necessitate a movement during one generation of not more than a mile. The discovery of migrations still in progress is accordingly removed from direct observation, except in the case of a few species, and any conclusions must depend entirely upon historical or indirect evidence.

HISTORICAL EVIDENCE OF MIGRATIONS.—Historical evidence may occasionally be used with considerable success, especially where civilization has existed for a long period of time and written records preserve trustworthy accounts of some of the original features of the vegetation. Thus Graebner[23] has been able to demonstrate that certain heaths of northern Germany were originally beech forests. Tansley[24] has also made frequent use of historical records. For the Middle West, such data cover little more than a single century and are correspondingly restricted in value. There are, however, numerous early books of travel which give fairly accurate accounts of the plant life. Their descriptions of prairie fires, of the former extent of prairies, and of the oak openings are in many cases excellent and may probably be relied upon completely. They generally lack detail and seldom mention many species by name, but are nevertheless better for phytogeographical purposes than the floras compiled by early botanists. In almost every county seat copies of the original land survey maps may be consulted. On many of them various features of the vegetation are shown, such as the occurrence of swamps, prairies, and barrens. In some cases the nature of the forest may be approximated by reference to the accompanying field books, since the surveyors' monuments were usually located with relation to certain described trees.

SUCCESSION AS EVIDENCE OF MIGRATION.—For migrations still in progress, the most valuable line of contemporary evidence is found in the successional relations of the species toward the margin of their ranges. Even there, succession can not generally be observed directly, but numerous other considerations offer convincing evidence of the nature of the process, such as the relation of the associations to physiographic development, the reaction of the plant cover on the environment, the presence and relative abundance of seedlings, or the relative age of individuals. These have been used so freely by ecologists and such a body of accepted data has been published that they need no discussion here. Nevertheless, a timely warning against the too general application of the principles of succession has been sounded by Harvey[25] and deserves careful consideration. When, at or near the margin of a range, a species or the members of a flora of uniform geographical distribution participates in successions as invading species, they are

[23] Graebner, P. Die Heide Norddeutschlands und die sich anschliessenden Formationen in biogischer Betrachtung. Die Vegetation der Erde, vol. 5, Leipzig, 1901.

[24] Tansley, A. G. Types of British vegetation. Cambridge, 1911.

[25] Harvey, Leroy H. Some phytogeographical observations in Lake County, Michigan. Mich. Acad. Sci. Rep. 21: 213–217. 1920.

extending their range. Similar behavior toward the center of the range may indicate only a general closing-up process, representing the later slower stages of a migration and not implying any general extension of range in the ordinary sense of the word.

The known successional tendencies of the three major types of vegetation of the Middle West have frequently been described, especially the tendency of the deciduous forests to succeed the prairies toward the west and the coniferous forests toward the north. Project this tendency into the future and it points to a still wider extension of this type of forest, with a corresponding restriction of prairie and coniferous forest. Project it into the past and it reveals a former condition of restricted deciduous forest and of a larger extent of prairie and coniferous forest. Obviously, such reasoning must not be carried too far, and its results must always be checked by the existence of relic species or relic colonies, as discussed in a following paragraph.

The stratigraphic sequence of fossils has been used with great success as one line of evidence in Europe.[26] While similar evidence has already yielded important results in America, the necessary data for extensive generalizations are usually lacking or deficient. The careful examination of the structure of peat has scarcely more than begun in this country, and the pioneer work of Dachnowski[27] may lead to important results.

Geological events must have necessitated certain migrations and by their very nature give a general idea of them. Thus it is incredible that beech-maple forests could have occupied northern Michigan during the maximum advance of the Wisconsin glaciers, which reached some 400 miles farther south. A northward movement of these trees and their associated species to their present location must have taken place after the retreat of the ice, but the details of this migration must be discovered by other lines of evidence.

Determining Migration Centers.—Adams[5] has advanced certain criteria for determining the migration-center of animals, which are in many cases equally applicable to plants. They are, with two omissions, as follows:

1. Location of greatest differentiation of a type.
2. Location of dominance or great abundance of individuals.
3. Location of synthetic or closely related forms.

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[26] Lewis, F. J. The plant remains in the Scottish peat mosses. Part I. The Scottish southern uplands. Trans. Roy. Soc. Edinburgh 41: part 3, 699-723. 1905.

[27] Dachnowski, Alfred P. Peat deposits and their evidence of climatic changes. Bot. Gaz. 72: 57–89. 1921.

4. Location of maximum size of individuals.
5. Continuity and convergence of lines of dispersal.
6. Location of least dependence on a restricted habitat.
7. Continuity and direction of individual variations or modifications radiating from the center of origin along the highways of dispersal.
8. Direction indicated by biogeographical affinities.

THE FIVE ELEMENTS IN THE FLORA OF THE MIDDLE WEST.—Applying his principles to the vegetation of the Middle West, it is found to be composed of five elements, not of equal importance, centering respectively in the southern Appalachian Mountains, in the southern Coastal Plain and the Mississippi Embayment, in the Ozark Mountains, in the plains of Kansas and Nebraska, and in Canada east of the Great Lakes. Four of these lie beyond the glaciated region far enough to have suffered little or not at all from the advance of the ice, and there is no reason to believe that they did not occupy these positions continuously through the later glacial period. The last one is in the glaciated region, and must have been developed since the retreat of the ice from a temporary refuge farther south. For the first four, we are probably safe in assuming that all subsequent migrations of their floral elements have been on lines essentially radial, either from or toward these centers, as ranges may have extended or retreated. For the fifth, we are undoubtedly correct in assuming a general northward shift of the whole flora following the ice retreat.

GLACIAL VS. MODERN CLIMATE.—The close similarity between the interglacial and the modern floras, so far as evidence is at hand, indicates that the glacial climate differed from the modern not so much in kind as in degree. It may be expected accordingly that migrations of the deciduous forests took place first in a northward direction from their Appalachian center and later westward into the Middle West, and that any eastward migration of a prairie flora took place toward the north of our area, where there is still a marked distinction between winter and summer rainfall and a generally smaller total amount, rather than at the south where rainfall is more abundant and more evenly distributed throughout the year.

Further evidence may be drawn from the topography of the region. Large and sharply marked moraines may indicate a rapid advance of the glacial ice. Wide stream valleys leading from the moraines, with great outwash deposits, may indicate rapid melting of the ice under relatively high temperatures, and consequently in the adjacent region a flora and vegetation correlated with such climate. Such evidence has been used chiefly in connection with the Wisconsin glaciation, where

it seems that the temperature at the time of maximum ice advance was high and probably not unlike that of the present time. The immature development of the drainage systems over the Wisconsin drift, particularly toward the west, may also be due not merely to youth but also to an early postglacial climate drier than that of the present day.

If a considerable number of species are now confined to an area immediately beyond a moraine and seldom or never occur within it, their distribution may be explained in several ways. First and most obviously, present conditions of soil and climate may exclude them. But if the general vegetation and climate of the two regions are similar and if habitats apparently identical, as judged by the vegetation, exist on both sides of the moraine, this explanation is less plausible. Secondly, their migration up to the present time may have extended merely to the moraine, which they will later cross. But it is difficult to understand why the boundary of the range of numerous species should be so nicely adjusted to the moraine. The third explanation, which is here accepted, is that they occupied this area before or during the formation of the moraine, have occupied it ever since, and are not at present extending their range.

Relic Colonies.—Lastly, and most important of all, past migrations may be judged by relic colonies. Unfortunately, they can be used only for the more recent movements, since the relics of earlier migrations have been completely destroyed. Many such colonies still exist, isolated by recent migrations, or did exist long enough to be recorded before being sacrificed to agriculture, and afford the most valuable evidence of the past range of the floras which they represent. They even give valuable clues to migrations of still earlier date, during which the flora of the colonies entered the region, and therefore show at once an early advance followed by a later retreat.

Although the probability of extreme migrations, except in the case of very mobile species, is very slight, the time available is very long and has certainly been sufficient for the improbable to happen many times. Therefore, in general, isolated stations of a single mobile species shed little light on its past history. But isolated colonies of several or many species, provided with diverse methods of dispersal, represent a different condition. It is entirely beyond the limits of probability or coincidence to presume that a dozen or more species, normally growing together in one section of the country, should also be found together in another remote section beyond the normal limits of dispersal of any of them. Isolated colonies of this character are common phenomena in the Middle West and can have but one significance, that at some time in the past these colonies were more numerous and separated by narrow

intervals within the normal migration-capacity of the species, or were entirely continuous over the whole area. Stated in more general terms, the present occurrence of relic colonies indicates the past extent of the vegetation of which they are a type. For the same reason, isolated stations of a single relatively immobile species indicate a former more nearly continuous distribution, and evidence from this source is of greater importance when the species in question is regularly associated with some peculiar or unusual habitat.

A combination of evidence from successional tendencies and relic colonies indicates both the direction and the extent of prehistoric migrations. The full extent may not be indicated, because the isolated colonies may have disappeared completely from the more remote parts of their original range. In such cases isolated stations of single species may give some not entirely untrustworthy idea of it. The farther back in time plant migrations are traced, the fewer relic colonies may be expected and the more dependence must be placed on individual species.

No one of these various lines of evidence is sufficient in itself to build up a history of vegetational movements in the Middle West. All of them must be used together and the deductions from all woven into a history which accounts for present conditions satisfactorily and is plausible in itself. The development of this history must be commenced with the present, where the latest migrations are shown by successional relations. The extent of these recent events may be estimated and checked by relic colonies, which in turn point to earlier migrations. These must be checked by glacial topography, by inferences concerning glacial climates, and by the distribution of plants along the moraines. Still farther back, plant distribution and migrations must be deduced from fossils, from the location of the moraines, from the known physiological requirements of the plants, and through the use of Adams' criteria.

The vegetational history which follows in Part IV has been constructed in this way. Observed conditions and recorded vegetational changes during the historical period have given evidence on migrations then in progress and permitted deductions as to those of the later prehistoric period. Conclusions as to the preceding stages have been reached through use of the various lines of evidence outlined above and carried back with decreasing detail and assurance to the advance of the Illinoian glaciers.

Summary of Part III.—1. Migrations in progress now or in the recent past are indicated by historical evidence or by observation of successions.

2. Former migrations are indicated by the occurrence and distribution of relic colonies and species, by ecological and taxonomic evidence as stated by Adams, by glacial history and topography, by fossils, and by inferences as to former climate.

3. Evidence from all available sources must be combined to build a plausible and possible chain of events, leading on to and culminating in the known present distribution of plants.

4. Conclusions as to early stages of plant distribution and migration are reached in reverse order of their occurrence, that is, from present to past. The accuracy of each conclusion depends on the accuracy with which the conditions of the following stage have been interpreted. Each earlier stage must therefore be discussed in less detail and with greater probability of error.

Part IV. The Development and History of Vegetation in the Middle West

Preglacial.—From the close of the Carboniferous Period to the Lower Cretaceous or Comanchean Period, the area now comprised between the Missouri Valley and the Appalachian Mountain system was continuously land. The pteridophytic and gymnospermous flora which occupied it can be partly reconstructed from the fossils of those ages, but its migrations are unknown. During the Lower Cretaceous the first representatives of the angiosperms must have arrived in our area, since the fossil remains of such plants are preserved in contemporary deposits still farther west, and through the Upper Cretaceous angiosperms constituted the dominant vegetation. It is not probable that herbs were prominently developed; angiosperms consisted chiefly of woody plants of families and genera still in existence in the area and of other groups now primarily or exclusively tropical. This flora is undoubtedly continuous with the forest flora of the Tertiary, usually designated the arctotertiary flora, and through it with the forests of the present.

While there may have been differentiation of floristic types in the Cretaceous, correlated with local climatic conditions, the first of the great vegetational segregations which is still of importance in our region began at the close of the Cretaceous with the uplift of the Cordilleran complex of mountains.[28] Intercepting the moisture-laden winds from the Pacific and restricting the rainfall of the lands immediately east of them to moisture derived from the Gulf of Mexico, the elevation of these mountains led to the development of semiarid conditions over the Great Plains, which soon had an effect on the

[28] Harvey, Leroy H., Floral succession in the prairie-grass formation in southeastern South Dakota. Bot. Gaz. 46: 81-108. 1908.

character of the vegetation. The result was the grassland type which still prevails in that region.

This result naturally required thousands of years for its accomplishment, but the *modus operandi* may be summarized as involving five processes: (1) the disappearance of the arborescent flora; (2) the great increase in the number of individuals of the herbaceous species; (3) competition for space among the herbs, leading to the eventual dominance of the grasses, as the group best suited by growth-form and ecological requirements to the new conditions; (4) the development by evolution of new and characteristic species and genera, and (5) the immigration, usually accompanied by specific or generic evolution, of other species from the Sonoran deserts at the south and the Great Basin deserts at the west.

How far toward the east the prairie vegetation may have extended in Tertiary time and how many advances and retreats it may have made in response to climatic variation are unknown. We may believe, however, that the present climatic center of the Prairie Province in western Kansas and Nebraska and eastern Colorado has been occupied by this vegetation continually since its origin, and that amoeba-like arms have been pushed out many times in many directions and withdrawn again. It is also probable that the arctotertiary forests have continuously occupied the Ozark uplift, since it still harbors many old species, although not so many as the Appalachian uplift of the same latitude, from which it was isolated during the Tertiary by the oceanic waters of the Mississippi Embayment. This isolation and the proximity of the Ozarkian region to prairie and Sonoran floras on the west have led to a considerable differentiation between the Ozarkian and Appalachian forest centers, as has already been noted in Part III.

Fossil evidence indicates that the arctotertiary flora included both angiosperms and gymnosperms and had little or no latitudinal differentiation, at least as far north as 70°. The second great floristic development affecting our region was the general segregation of these two groups into a northern flora, with gymnosperms predominating, and a southern flora, in which angiosperms were dominant. This probably began only with the approach of the first glacial period and may not have been completed until the ice age was well under way. The processes were essentially the same as those outlined above for the prairie vegetation, but in this case involved also the permanent disappearance from both floras of a number of species belonging to genera whose modern representatives are tropical. The former presence of *Ficus, Artocarpus, Sabal,* and other genera of similar climatic requirements in northern latitudes has frequently been taken to indicate a tropical or subtropical climate in those regions. The writer sees no

reason for believing that such genera could not have produced species adapted to a temperate climate then, just as *Phoradendron, Diospyros,* and *Tripsacum* have at present, so that the actual shift of climate northward may have been only a few hundred miles.

These three floristic and vegetational types have since maintained their identity, and the history of the vegetation of the Middle West is concerned almost exclusively with them. A fourth floristic element, the Coastal Plain flora of the southeastern states, was likewise segregated from the arctotertiary forests, probably during the late Tertiary or Pleistocene, and enters the southern portion of our region, but has probably never occupied a more extensive territory than at present. The Coastal Plain flora has been considerably modified by the immigration, accompanied by evolution, of numerous tropical forms, entering the region via Texas or the Florida peninsula. Some of these have extended still farther north and have invaded other floras as well.

EARLY GLACIAL STAGES.—There is no present evidence concerning the migrations of vegetation during the Nebraskan and Kansan glacial advances, at least one of which entered our area, or during the corresponding Aftonian and Yarmouth interglacial stages, and the earliest evidence at hand deals with its location during the Illinoian period at the time of maximum advance of the ice.

The southern boundary of Illinoian glaciation extends in a generally southwesterly direction across Ohio and Indiana and lies on the northern slope of the Ozark uplift in southern Illinois. It then turns northward, following in a general way the present course of the Mississippi river to the Wisconsin border, displacing the river westward in eastern Iowa, but passing to the east of the driftless area in northwestern Illinois. Its deposits in Wisconsin are almost wholly covered by those of a later period and its further extent in the Middle West is unknown.

The pre-Illinoian flora of the territory covered by this ice sheet must have been destroyed or have migrated south, west, or in both directions. The immediate problems are to ascertain the distance beyond the glacial boundary to which it was forced and the location of the extraglacial floras during the time of maximum ice advance. Several features of present distribution seem to cast some light on the questions.

The Mississippi Embayment.—The Mississippi embayment of southern Indiana, Illinois, and Missouri is occupied by a large number of species which reach here their northern limits in the extensive floodplains of the Ohio, Wabash, and Mississippi rivers, without migrating farther to the north along these floodplains into glaciated territory.

Noteworthy among them are *Taxodium distichum*,* *Rhamnus caroliniana, Gleditsia aquatica, Nyssa aquatica, Ilex decidua, Catalpa speciosa, Fraxinus profunda, Celtis mississippiensis, Quercus Phellos, Leitneria floridana,* and a host of other shrubs and herbaceous species. Soil conditions can not be cited as the cause of this range, because the soils in which these plants grow is all alluvial, washed down by the streams from the glaciated region, and parallels them without any essential difference for miles within the glacial boundary. Neither can climate be cited, since two of them, *Taxodium distichum* and *Catalpa speciosa,* are commonly, and others occasionally, cultivated 200 to 300 miles north of their natural limits.

Northern Limits of Southern Plants.—The rocky hills of the Ozark uplift in southern Illinois also carry a number of southern plants which reach here their northern limits, such as *Pinus echinata, Batodendron arboreum, Ulmus alata, Azalea nudiflora, Bumelia lycioides, B. lanuginosa,* and many others. These also have failed to utilize the extensive strip of similar habitats along the rocky bluffs of the Mississippi river for further migrations into the glaciated region. Still other species have interesting ranges correlated in some way with the glacial boundary. Thus *Heuchera parviflora* occupies isolated areas along the boundary only, with the exception of its stations in the lower Allegheny mountains. *Trichomanes Boschianum* preserves an outpost in southern Illinois, where it has recently been discovered by Cowles. *Sullivantia Sullivantii* occurs only along the glacial boundary from Ohio to Illinois and reappears in the driftless area 300 miles to the north. *Saxifraga Forbesii* is strictly limited to two stations along the glacial boundary in southern Illinois and southeastern Missouri. *Phlox Stellaria* is chiefly confined to certain limestone cliffs along the glacial boundary in Illinois and not far beyond it in Kentucky.

Undoubtedly there are species which reach their northern limit near the glacial boundary because of climatic conditions. This might be true of *Phoradendron flavescens,* whose host trees are abundant north of the boundary, but which has not crossed itself. But with numerous species with coincident range margins at this line, and several species with isolated stations near it, an easier explanation is that they remained here during the glacial period and have not migrated northward since then, indicating that the northern boundary of the arctotertiary forests lay parallel with and close to the ice margin.

There is at present no evidence whether this forest flora at that time extended westward toward the Ozarks, leaving northern Missouri

* A single colony occurs in Knox County, Indiana, within the glaciated area.

and Iowa to a prairie flora of western affinity, or northward along the western boundary of the ice fields, restricting the prairie to a location farther west. Extensive forest beds overlie the Kansan drift in northeastern Iowa, as shown by McGee,[29] who states that more wood is preserved in these beds than at present grows in the area, but the time-position of these forests may be either Yarmouth, Illinoian, or Sangamon.

The Migration of the Conifers.—The conifers of the present northeastern forests, or their ancestral prototypes, migrated southward before the ice and must have been reduced to a narrow strip between the ice margin and the deciduous forests. There is no evidence whether this flora extended west as far as southern Illinois or existed in the unglaciated region of northwestern Illinois. It is noteworthy that *Pinus Strobus* does not occur on the exposures of St. Peter's sandstone near the confluence of the Mississippi and Illinois rivers, but its absence proves nothing. The only species of essentially boreal affinity now existing in southern Illinois are *Sullivantia Sullivantii* and *Saxifraga Forbesii,* and it is not necessary to presume that they were ever accompanied by coniferous forests. Such forests may have existed anywhere along the glacial margin, or may have been restricted to some especially favorable area, such as the re-entering angles in Ohio and Indiana, or to the mountains of Pennsylvania and adjacent states. The prominent development of vegetation of this affinity in the southern Allegheny mountains may have arisen during a later glacial advance or may have persisted since the Illinoian.

The Migration of Deciduous Forests.—During the long Sangamon interglacial stage which followed the retreat of the Illinoian glaciers, deciduous forests undoubtedly migrated to the north and probably also to the west. The full extent of this migration can at present only be surmised, since it must be ascertained wholly by fossil evidence, and this is in most cases lacking. Nevertheless, logs of both angiospermous and coniferous species are found frequently in the soil layer between the Illinoian drift and the superposed Wisconsin soil in various parts of Illinois. Leverett[30] has noted that the coniferous remains must not be considered evidence for the maintenance of such forests throughout the interglacial stage, since they probably were deposited at the end of it, just before the approach of another glacier. The notable discoveries in the vicinity of Toronto, summarized by Chamberlin and

[29] McGee, W. J. The pleistocene history of northeastern Iowa. U. S. Geol. Surv. Ann. Rep. II[1]: 189-599. 1891.

[30] Leverett, Frank. The Illinois glacial lobe. U. S. Geo. Surv, Mon. 38. 1899.

Salisbury,[31] indicate that deciduous trees may have migrated during the Sangamon stage to distances some 500 miles beyond their present range.

There must have been other vegetational movements during the Iowan glaciation and the succeeding Peorian interglacial stage, but no evidence concerning them has been found, and none is expected from the region under discussion, except from fossils which may eventually be discovered in the Peorian soils. The Peorian stage may have had a relatively warm and arid climate, since during this time extensive deposits of loess were made over wide areas in the Middle West. This type of climate may have persisted into or even through the Wisconsin glaciation.

Wisconsin Glacial Period.—The close of the Peorian interglacial stage saw the advance of the Wisconsin glaciers, which as the last glacial invasion have left the greatest impress on the nature and location of the present vegetation. Originating in the Labradorian center, the ice sheet flowed in a southwesterly direction into our area, wholly covering the state of Michigan and partially covering Ohio, Indiana, Illinois, and Wisconsin. Toward the periphery, the ice sheet was divided into more or less well-marked lobes, with re-entering angles between them. The ice margin along the eastern boundary of Ohio reached nearly to the northern extremity of West Virginia, extended across Ohio in a generally southwesterly direction to a point not far north of Cincinnati, westward across Indiana in about latitude 39° 30′, westward into Illinois, and thence northward on about longitude 89° to latitude 45° in Wisconsin. Here the boundary again turned west, and another lobe extended south into the north-central portion of Iowa. Throughout this area there is an extensive development of moraines, the chronological relations of which have been discussed in admirable detail by Leverett[30,32,33] and Alden.[34] These moraines mark successive stages in the retreat of the ice, and it is to be hoped that the application of De Geer's methods to the region will eventually yield an approximate time-scale for their history, an event which will be of the highest importance in developing a clear idea of the consequent migrations of vegetation. At the same time, a continued study of the

[31] Chamberlin, T. C. & R. D. Salisbury. Geology. New York, 1907

[32] Leverett, Frank. Glacial formations and drainage features of the Erie and Ohio basins. U. S. Geol. Surv. Mon. 41. 1902.

[33] Leverett, Frank, & Frank B. Taylor. The pleistocene of Indiana and Michigan and the history of the Great Lakes. U. S. Geol. Surv. Mon. 53. 1915.

[34] Alden, Wm. C. The quaternary geology of southeastern Wisconsin, with a chapter on the older rock formations. U. S. Geol. Surv. Prof. Paper 106. 1918.

peat deposits[27] is certain to yield precise information concerning the nature of the flora.

Outside the margin of the Wisconsin ice lay the five floristic groups of plants already mentioned, the prairie flora to the west, the Ozarkian forests to the southwest, the coastal plain flora of the Mississippi Embayment to the south, and the deciduous forests of the Appalachian and Piedmont regions to the southeast, while the coniferous forests of the present northeastern states were limited to a belt paralleling the glacial margin. There is no reason to believe that the general space relation of these five groups has ever been altered, although they must have suffered many fluctuations in their distribution and extent during the preceding glacial advances.

With the retreat of the ice, the new glacial soil was thrown open to migration and speedily covered by plants. Adams has given a picturesque account[6] in general terms of the waves of vegetation which swept on to the north as the ice margin retreated. But postglacial migration was by no means as simple as he has described it, particularly because of the opportunities for migration in easterly and westerly directions as well as toward the north. It is also obvious that the advantage in migration lies with the floristic type located nearest to the new land. Hence it is important to locate the five floristic types as accurately as possible for the time of maximum advance of the Wisconsin ice.

Distribution of Plant Life During the Wisconsin.—When it is considered that the past distribution of plants can in general be interpreted only through circumstantial evidence, it becomes hazardous to venture any opinion on the actual details of plant distribution during this period. Nevertheless certain modern conditions are of interest in this connection.

The glacial drift of southern Illinois beyond the Shelbyville moraine, which marks the southern boundary of the Wisconsin glaciation, is characterized by a large number of more or less xerophytic species. Among these may be mentioned *Ambrosia bidentata, Ascyrum hypericoides, Chamaecrista nictitans, Crotalaria sagittalis, Crotonopsis linearis, Diodia teres, Diospyros virginiana, Galium pilosum, Parsonsia petiolata, Passiflora lutea, Plantago aristata, Plantago virginiana, Quercus marylandica,* and *Quercus stellata.* Few of these are native anywhere within the Wisconsin drift limits, although several of the weedy species have within recent years migrated northward and are now found rather uniformly throughout Illinois. They may be described collectively as xerophytic selections from a southern flora. The same region is also marked by a few rather peculiar xerophytic

selections from a western or southwestern flora, not found elsewhere in the state, such as *Geoprumnon mexicanum* and *Megapterium missouriense,* but it must be noted that these are much fewer than the southern element, and also much fewer than species of the same western element in western Illinois.

Some of the most noteworthy mesophytic trees are nearly or quite absent from the same region, such as *Fagus grandifolia, Cynoxylon floridum, Liriodendron Tulipifera,* and *Magnolia acuminata,* although some of them extend much farther north in almost the same longitude and all of them, crossing Illinois at its southern end, extend westward as far as the Ozark mountains.

The Ozarkian flora at the present time barely reaches Illinois. A few species occur on the rocky hills of the Ozark uplift, such as *Solidago Drummondii* and *Solidago Radula; Trillium viride* occurs northeast of St. Louis, but in general the flora is poorly developed east of the Mississippi, although strongly marked only a few miles west of it. Even such a mobile species as *Vernonia Baldwini,* common in the vicinity of St. Louis, is scarcely known on the Illinois side. There is no evidence as to the date when this flora appeared in Illinois, and no reason to believe that it ever extended farther east or took a more prominent part in the plant life of the region.

In western Illinois, beyond the Wisconsin drift, north of the low range of hills which divided the Illinoian till into two portions (see Leverett's map[30]), and mostly west of the Illinois river, there are a number of intensely xerophytic western species, such as *Bouteloua hirsuta, Bouteloua oligostachya, Schedonnardus paniculatus, Opuntia fragilis, Mentzelia oligosperma, Lesquerella argentea,* and *Cristatella Jamesii.* They are not merely xerophytes, but are limited to peculiar and extreme habitats. They have not been reported east of the terminal moraine, even from similar habitats on the sand dunes of Lake Michigan. *Schedonnardus paniculatus,* with a single station in Illinois, and *Cristatella Jamesii,* with two known stations in Illinois and one in eastern Iowa, present excellent examples of discontinuous distribution, since their nearest stations to the west are 300 to 500 miles away. Such distances are much beyond the normal range of their migration and these eastern stations must be regarded as the relics of a former nearly continuous range across eastern Nebraska and Iowa. This in turn implies a climate some time in the past much drier than at present. There are also in this part of the state a few xerophytic southern plants, such as *Quercus marylandica* and *Crotonopsis elliptica,* but their successional relations indicate a later arrival in the region.

It has been indicated that coniferous plants during the Illinoian glaciation must have been confined to a narrow strip paralleling and adjacent to the ice margin. The same conditions must have obtained during the Wisconsin. The lack of relics of this flora along the Shelbyville and Bloomington moraines is striking. From Edgar County, Illinois, where the terminal moraine enters the state from Indiana, west and north to La Salle County, almost no boreal relics occur. The absence of pines may well be explained by the soil conditions, but the swamps and bayous of the rivers are also without *Larix* and *Thuja* and any of the ericads of the peat bogs of the north; even *Caltha palustris* and *Spathyema foetida* are almost unknown along the glacial boundary until well towards the northern end of the state, although most of these plants are found freely along the moraine in similar latitudes in Ohio and some in Indiana. At the north they reappear: *Abies balsamea* occurs in northeastern Iowa, and *Pinus Strobus* is abundant from southwestern Wisconsin northward. Even *Primula Mistassinica* occurs in northwestern Illinois.

All of these facts of modern distribution may be explained by postulating a glacial climate during the Wisconsin considerably drier than at present and not much different in temperature, so that the vegetation of extra-glacial Illinois assumed a xerophytic aspect. Under this view, we may assume that the Ohio valley in southern Indiana and Illinois was occupied by its present forest flora, possibly not so luxuriantly developed; the Illinoian drift to the north of it by a xerophytic forest of southeastern affinity with a slight admixture, decreasing toward the west, of a prairie element; western Illinois was exclusively prairie, of a type similar to that now prevailing possibly 400 miles farther west. A narrow and interrupted strip of coniferous forest followed the glacial boundary, especially in places where greater topographic relief afforded better shelter. Toward the east, across Indiana and Ohio, the strip became broader and included more species. Toward the north it broadened out again in the driftless area in the shelter of the deep rocky ravines, with the additional protection of the projecting Des Moines lobe of ice extending southward to the west of them. It is doubtful if any conifers or associated species occurred west of this lobe. Tundra vegetation, less affected by the environmental conditions, grew on the thin soil overlying the ice back of the glacial margin. In general, the climatic conditions and vegetation may have been shifted in this latitude 300 to 400 miles east of their present location. The presence of an old flora in the Ozarks indicates that this shift did not extend much farther toward the south.

There is also some geological evidence of a climate during Wisconsin time well suited to a xerophytic vegetation. Various rivers of the region, notably the Wisconsin, the Green, and the Illinois, which rise within the Wisconsin drift and flow out to the west or southwest, occupy beyond the Wisconsin terminal moraine valleys entirely out of proportion to the size of the present rivers and choked with immense quantities of glacial outwash. This may indicate unusually rapid melting, due to a mild (and presumably also a dry) climate.

During this period, forest belts of the more mesophytic species may have existed along the Mississippi, Wabash, Illinois, Missouri, Cedar, and Des Moines rivers in the eastern portion of this semi-arid region, just as they do today in a similar climate in Nebraska and Kansas.

Climate in the Early Post-Wisconsin.—Whether or not the conclusion is accepted that a mild and semi-arid climate existed in the Peorian and persisted through the Wisconsin stages, it seems almost certain that such a climate characterized at least a portion of the time involved in the post-Wisconsin glacial retreat. Palaeontological and geological evidence for such a condition is scanty, and is concisely summarized by various authors in a recent volume.[35] Alden [35a] believes "that during the deposition of the post-Wisconsin loess the climate in the northern interior may have been somewhat drier than at present, but was not greatly different." Knowlton says [35e] "There is some little palaeobotanical support for the contention that there was a slightly warmer period following the close of the glacial epoch." Tyrrell concludes[35f] that the glacial climate of the Canadian northwest was "succeeded by a dry continental climate, under neither of which conditions was a forest growth possible." Basing his opinion on the occurrence of certain animal remains, Hay believes [35d] "that after the retreat of the ice-sheet a warmer period ensued," at the culmination of which "the region along the southern shores of Lakes Ontario, Erie, and Michigan enjoyed a climate similar to that now prevailing in Tennessee

[35] Die Veränderungen des Klimas seit dem Maximum der letzen Eiszeit. Eine Sammlung von Berichten . . . herausgegeben von dem Exekutivkomitee des 11. Internationalen Geologenkongresses. Stockholm, 1910. Including:

[35a] Alden, Wm. C. Certain geological phenomena indicative of climatic conditions in North America since the maximum of the latest glaciation. 353–363.

[35d] Hay, O. P. On the changes of climate following the disappearance of the Wisconsin ice sheet. 371–374.

[35e] Knowlton, F. H. The climate of North America in late glacial and subsequent post-glacial time. 367–369.

[35f] Tyrrell, J. B. Changes of climate in northwestern Canada since the glacial period. 389–391.

and Arkansas." Similar opinions have also been expressed by Coleman, Matthew, Dawson, Leverett, Upham, and Davis.

The same period was early recognized in Scandinavia by Blytt[36] and has been generally accepted by most European phytogeographers. Of the numerous papers on the subject published in the same volume, those of Andersson [35b-c] seem especially conclusive. He decides that during the early postglacial stages the climate of Scandinavia had winters similar to those of the present, while the summers were longer and about 2.5° C. warmer. Later the climate became wetter, while remaining equally warm, while for the modern period there is evidence of a slow lowering of the temperature. It is also worthy of note that Andersson lays great stress on the value of relic colonies as evidence of past distribution.

The term xerothermic period has long been used by Europeans for this period of mild and drier climate, and may well be extended to the same type of climate, probably contemporaneous, in America.

A xerothermic period, occurring in comparatively recent times, and without any subsequent geological episodes to modify greatly the trend of plant migrations, would certainly have left an impress on the distribution of vegetation which would still be visible. Among the effects which might be expected is a great extension of the prairie flora toward the east, taking advantage of the favorable climate. This should now be evidenced by relic prairie colonies and by isolated stations of western species at the east and by a deficiency of hydrophytic and mesophytic boreal relics at the west. Both of these results are actually demonstrable at the present time, as will be shown below. A third effect should be seen in the migrations of the deciduous forests from the southeastern center, in which the more mesophytic species would be limited at first to a northward migration only, passing to the east of the area affected by xerothermic conditions, while the more xerophytic species would migrate both north and west, accompanied by other species of edaphically moist floodplains, such as now form the westernmost groves of Kansas and Nebraska. Present distribution indicates that this was also a fact, although it is less clearly evident at the present time.

Tundra and Coniferous Forest Migration.—The northern boundary of the tundra vegetation overlying the glacial ice extended toward the north with the retreat of the ice. At its southern boundary,

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[35b] Andersson, Gunnar. Das spätquartäre Klima, eine zusammenfassende Uebersicht. xii-lvi.

[35c] Andersson, Gunnar. Swedish climate in the late-quaternary period. 247-294.

[36] Blytt, Axel. Dia Theorie der wechseluden kontinentalen und insurlaren Klimate. Engler's Bot. Jahrb. 2: 1-50. 1881.

the tundra persisted until destroyed by the warmer climate or by the succession of the coniferous forests. In general, tundra withstands a climate slightly warmer than its optimum better than the competition of forest species, which quickly destroy it by shading.[22] As in all such retreating migrations, relic colonies were isolated, surrounded by the advancing forests, and persisted for a longer or shorter time until finally completely overgrown by the spruces and firs. Naturally those endured the longest which occupied habitats least favorable to forest growth. We may presume that the sand dunes along the shores of the postglacial lakes and such isolated rock outcrops and cliffs as Starved Rock in Illinois and the Dells of the Wisconsin River were for a long time occupied by tundra plants, just as they are now occupied by relics of the coniferous forests. The xerothermic period and ordinary successional processes have long since destroyed the last vestige of tundra vegetation in these latitudes, and the southernmost species are now found scarcely farther south than Lake Superior. On Isle Royale[27] associations still exist which bear a general resemblance to the arctic tundra and contain a few species of distinctly northern distribution. As the tundra migrated northward into cooler and moister regions, and the cooling influence of the ice was felt farther beyond its margin, the belt of tundra broadened, that is, it migrated toward the north faster than it retreated from the south, until it now occupies an area some hundreds of miles wide.

The boreal coniferous forests which had occupied a narrow or interrupted strip along the glacial margin during the Wisconsin stage also migrated northward following the retreat of the glaciers, surrounding the relic colonies of tundra and eventually replacing them by succession. The pioneers in the movement were probably then as now the xerophytic species advancing along the rock outcrops and till of the upland, and the bog species proceeding along the drainage lines and the glacial lakes. These forests also advanced toward the north faster than they retreated from the south, and consequently occupied a strip of increasing breadth. This led to their present dominance over a large area north and east of the Great Lakes and to their temporary dominance, which is still continued in many habitats, in northern Minnesota, Wisconsin, and Michigan. Their northward movement brought the conifers into climates progressively cooler and relatively moister. This led not only to a greater number and size of individuals, but also permitted a northwestward migration into northern Minnesota and Manitoba. This northwestern prolongation was eventually extended,

[27] Gleason, H. A. The ecological relations of the invertebrate fauna of the Isle Royale, Michigan. Rep. Mich. Geol. Survey 1908: 57-78. 1909.

with the complete disappearance of the land ice, as far as Alaska. Since the morainal strip of boreal vegetation was, in the Middle West at least, always narrow, frequently interrupted, and probably completely absent about the Des Moines lobe, and composed chiefly of a xerophytic selection of species, the western end of the forest belt was composed, during its advance to its present location, of a comparatively meager flora. Each mile of advance to the northward saw the widening of the belt and the junction of portions previously isolated, and consequently permitted a westward migration of species from the eastern states, which were little affected by the xerothermic climate. This westward migration has by no means been completed and is probably even now in progress through the forests of Quebec and Ontario, but the boreal flora of the upper Lake region is still poor in comparison with that of Quebec, New Brunswick, and the New England states. The northwestern extension across Manitoba to Alaska shows a progressive diminution in the number of species concerned, as graphically shown by Transeau's[38] map.

When these forests reached the eastern foothills of the Rocky Mountains in Alberta, they were again in contact with the closely related species of the Pacific Conifer Province, from which they had long been separated. It will be interesting to learn from future studies what exchange of species now took place; whether widely distributed species common to both regions, such as *Populus tremuloides,* had been in both since their segregation; whether the numerous Pacific plants of the St. Lawrence valley are preglacial members of the northeastern flora, or migrated eastward at this comparatively recent stage. It is not too much to expect that all of these matters are possible of solution.

In this migration of boreal plants, numerous relic colonies were left behind. Many of them have since disappeared before the encroachment of surrounding vegetation or the changes in climate, but thousands still exist. As is generally the case with relic colonies, they occupy for the most part extreme habitats, either xerophytic rock hills and sand dunes, clothed with *Pinus Strobus* and *Pinus Banksiana,* or bogs, characterized by *Larix laricina* and *Thuja occidentalis.* It is especially noteworthy that in Ohio, where the influence of xerothermic conditions was reduced by the eastern position, the hydrophytic colonies persist farther south than the xerophytic. In Illinois the condition is reversed, and neither of the two hydrophytic trees is reported from Iowa. Tamarack bogs are found in Illinois only along the borders of deep lakes in the immediate vicinity of Lake Michigan, while *Pinus Strobus*

[38] Transeau, Edgar N. Forest centers of eastern America. Amer. Nat. 39: 875-889. 1905.

occurs not far from the Mississippi and in one county in southeastern Iowa. The occurrence of boreal relics in the driftless area of northeastern Iowa has already been noted.

Ponds were abundant on the Wisconsin drift in Illinois half a century ago, and were notable for the complete lack of such hardy boreal plants as *Comarum palustre, Dulichium arundinaceum,* and *Menyanthes trifoliata.* They were mostly shallow and easily drained and have long since disappeared. They were also characterized by the absence of deep peat deposits, indicating that they had never been occupied by boreal vegetation and were of comparatively recent origin. The carefully prepared reports of the Illinois soil survey present interesting figures concerning them. Ten counties of central Illinois contain only 1,986 acres of deep peat, or 0.04% of their area, and of this 1,779 acres lie in the floodplain of the Illinois River. Three counties of north-central and northern Illinois contain 0.15% of deep peat, one county in the Kankakee valley 0.83%, while three counties of northeastern Illinois contain 4.67%. Even in southern Michigan, far within the boundary of the Wisconsin deposits, only the deeper lakes are bordered by tamarack bogs. This lack of hydrophytic boreal relics toward the southwestern angle of the Wisconsin glaciation is best explained by the assumption of the xerothermic period, as already noted, during which hydrophytic habitats were obliterated toward the west, except in the deepest depressions or in local areas affected by subsurface water,[39] thereby restricting the relic colonies chiefly to the xerophytic types.

Early Migration of the Prairie Flora.—An advance of the prairie vegetation toward the east and northeast followed immediately behind the coniferous forests, displacing the rearguard of the forest by successional processes. There is now no place in the Middle West where grassland is succeeding forest, and it becomes difficult to picture the detailed steps by which such succession proceeded. In bogs, as the climate grew warmer, and the ingress of water was reduced with increasing distance from melting ice, the gradual drying may have inhibited the growth of seedlings and permitted the entrance of prairie species. This process is now seen in modified form in southern Michigan, where partial drainage of tamarack bogs leads to the displacement of the usual bog shrubs by *Dasiphora fruticosa.* On uplands, the exposure of the marginal trees to warm and dry winds during the summer, with consequent injury through excessive transpiration, may

[39] Gates, F. C. A bog in central Illinois. Torreya 11: 205-211. 1911.

have had the same effect,[40] while severe winter-killing among young plants may have resulted from deficient snow cover.[41,42]. Certainly the fewest boreal relic colonies are now found in southern Wisconsin and southeastern Minnesota,[43] where such atmospheric conditions are still more or less in effect.* Geographically the advance of the prairies was favored by the slow withdrawal of the eastern ice northward and the rapid retreat of the western ice northeastward, thereby opening to invasion first Illinois and then Indiana. A slight change in the nature of the ice retreat might have affected the future vegetational development of the region very greatly.

The distance to which the prairie vegetation migrated northward is not definitely known. Very likely it reached in central Michigan as far as the jack pine plains, which still contain numerous prairie species, and if this is true must have reached similar or even higher latitudes in Wisconsin. There is no present reason to believe that prairies were developed on the north shore of Lake Erie. Deciduous forests in Minnesota now occupy a narrow strip between the prairie and the coniferous forests, and it is probable that their entrance was about equally at the expense of the two earlier types of vegetation. If this is true, the prairies did not extend much beyond their present range in that state.

The eastern migration of the prairie proceeded as a wedge-shaped extension between the coniferous vegetation at the north and the deciduous forests at the south and reached limits considerably beyond the eastern margin of modern continuous prairies. Numerous relic colonies formerly occurred, before they were destroyed by agriculture, in eastern Indiana, northwestern Ohio, and southern Michigan[44] (see also Cooper's description of an oak opening in his novel of the same name). Vegetation closely simulating typical prairie exists along the Scioto River near Columbus, Ohio. Bonser[45] has described a marshy tract near Sandusky, Ohio, which still contains some western species, notably *Vernonia fasciculata*. This so-called prairie has doubtless

* Contrast maps in references 37 and 42.

[40] Shimek, B. The prairies. Bull. Lab. Nat. Hist. Univ. Iowa 6[2]: 169-240. 1911.

[41] Gates, F. C. The relation of snow cover to winter killing in *Chamaedaphne calyculata*. Torreya 12: 257-262. 1912.

[42] Gates, F. C. Winter as a factor in the xerophily of certain evergreen ericads Bot. Gaz. 57: 445–489. 1914.

[43] Livingston, B. E. A study of the relation between summer evaporation intensity and the centers of plant distribution in the United States. Plant World 14: 205–222. 1911.

[44] Gleason, H. A. A prairie near Ann Arbor, Michigan. Rhodora 19: 163-165. 1917.

[45] Bonser, Thomas A. Ecological study of Big Spring Prairie, Wyandot County, Ohio. Ohio Acad. Sci. Special Paper 7. 1903.

preserved its hydrophytic environment since an early period, being watered by springs, and consequently contains a considerable number of boreal species, notably *Betula pumila*. *Opuntia humifusa* occurs near the same place. Species of distinctly western affinities do not occur on Presque Isle, near Erie, Pennsylvania,[46] and the abundant development of boreal species and the typically Alleghenian aspect of the flora in northeastern Ohio make it reasonably certain that extensive prairies were not developed east of Cleveland.

The unglaciated areas of southern Ohio, Indiana, and Illinois, and the Ozark region of southern Missouri are now populated with a forest flora that presents indications of great antiquity, and in their greater topographical relief offer better opportunities for forest species to endure unfavorable atmospheric conditions. It seems reasonably certain that the prairies did not encroach on this area at any time. Probably the southern boundary of the glaciated area marked the division between forest and prairie, and probably forest belts followed even then the courses of the rivers northward well into the prairie region. The forest belts of the Mississippi may have been derived from the southern species of the Mississippi embayment; at the present time several of them follow the course of this river northward, such as *Gleditsia aquatica* and *Hicoria Pecan*. No evidence is now at hand concerning the possible extent of the prairie into the Ozark region of southwestern Missouri and northwestern Arkansas. What relation the xerothermic period may have had to the barrens of Tennessee, the prairie belt of central Alabama, the prairies of eastern Arkansas, and the coastal prairies of Louisiana must be left to the deductions of observers who have had personal experience with the vegetation of these areas.

In further support of the idea of a xerothermic period, it need only be recalled that the discontinuous distribution of such plants as *Opuntia fragilis* and *O. humifusa*, *Sporobolus heterolepis*, *Cristatella Jamesii*, and *Callirrhoe triangulata* can be adequately explained only by assuming a former period of climate sufficiently drier than the present to permit their continuous migration. This, with the existence of relic prairie colonies at the east and the prevailingly xerophytic nature of the relic boreal colonies at the west, seems to be sufficient evidence of the actuality of a post-Wisconsin xerothermic period.

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[46] Jennings, Otto E. A botanical survey of Presque Isle, Erie County, Pennsylvania. Annals Carnegie Mus. 5: 289–421. 1909.

The eastward advance of the prairies was either accompanied or followed by some specific evolution among the species participating, as indicated by such plants as *Phymosia remota*,[47] *Synthyris Bullii*, and *Tetraneuris herbacea*. These plants are now confined to the eastern arm of the Prairie Province, but in each case have their nearest related species much farther west.

There is no reason to suppose that the xerothermic period came to a sudden close, which would require an equally sudden geological event in explanation. In fact, it may have been most pronounced during the Wisconsin glaciation and diminished in intensity ever since, but not sufficiently to check the rapid advance of the prairies behind the retreating coniferous forests. Neither can the time of maximum advance of the prairies be correlated at present with the postglacial stages of the Great Lakes.

EARLY MIGRATIONS OF THE DECIDUOUS FORESTS.—At some time an amelioration of the climate began. This change was probably less connected with temperature, which has doubtless changed but little in our area since the Wisconsin glaciation, than with rainfall and atmospheric humidity. The total rainfall probably increased considerably, but the increase fell chiefly during the winter months and changed the climate from one of summer rains, such as is now characteristic of the prairies farther west, to one of fairly equable rainfall. This change first made itself felt in the east and gradually progressed toward the west. At the present time, each hundred miles west of the Wabash River along the fortieth parallel shows a marked diminution in winter rainfall.

The effect of this climatic change was the retardation and eventual cessation of the old successional relation between coniferous forest and prairie, soon followed by a break in the equilibrium along the southern and eastern margins of the prairies, leading to an advance of the deciduous forests northward and westward.

Two general routes were followed in this forest migration, a northward and westward route from the forests along the southern edge of the prairies and a northward and then northwestward route from those lying east of the easternmost extension of the prairies. Many species were common to both regions and participated in both migrations; others were localized and show by their present distribution that they entered the Middle West by only one of these routes. Both took place simultaneously, and in some places both migrations eventually met,

[47] Clute, W. N. The rarest American Plant. Amer. Botanist 26: 127–129. 1920.

so that races of similar ultimate ancestry but of different recent history are again growing together.

The Southern Migration.—The southern migration was participated in chiefly by oaks and hickories of the drier uplands, and by oaks, elms, ashes, walnuts, maples, hackberry, cottonwood, honey locust, coffee tree, buckeye, and sycamore of the lowlands. Following as closely behind the prairies as environmental change would permit, these plants established two successional series, a xerarch series on the uplands, leading to the establishment of an oak-hickory forest, and a hydrarch series along the stream valleys, leading to the development of marginal belts of hydrophytic or mesophytic forest. The hydrarch series migrated more rapidly up the stream courses, since the species concerned could take advantage of local conditions of favorable moisture, while the xerarch series found its most favorable route along the broken topography of the river bluffs, between the prairies above and the hydrarch forests below. The two types of forest thus advanced upon the prairies together along the river courses leading southward into the Ohio valley and eastward into the Mississippi, and the present outposts of this migration are still to be seen in Kansas, Nebraska, the Dakotas, and Manitoba on the west and in Michigan and Wisconsin on the north.

Some of the mesophytes were left far behind in this advance, and the beech, sugar maple, tulip tree, and basswood are not particularly important members of the climax forest or even totally absent from Illinois west. In such cases a temporary climax developed in ravines and on floodplains and was composed chiefly of a selection of species persisting from the earlier successional stages. The slower trees have been migrating, nevertheless, and with the greater success the farther east. Beech is common in the Ohio valley: it has scarcely moved up the Mississippi, but has followed the Wabash well into Indiana, and the Miami, Muskingum, and Scioto until Ohio is occupied by it completely. There is reason to believe[48] that large areas of forest were developed on the uplands in which the most mesophytic tree was the red oak, *Quercus rubra*.

The Northern Migration.—The northern migration proceeded from the deciduous forests which had had a glacial center of preservation in the Allegheny Mountains from Pennsylvania southward. These species, now constituting the well known Alleghenian element in the flora of New York and New England, have been during and since the

[48] Gleason, H. A. An isolated prairie grove and its phytogeographical significance. Bot. Gaz. 53: 38–49. 1912.

glacial period more or less mixed with boreal elements, and this condition has been increased by their postglacial migration into a country from which the coniferous forests were retreating and leaving numerous relics behind, without an intervening prairie stage. Moving slowly northward behind the glaciers, which occupied the Ontario basin long after migration routes farther west were open, a portion of the species concerned finally turned to the west and northwest and entered Michigan, Wisconsin, and Minnesota, while others, such as *Quercus Prinus,* moved scarcely west of the Appalachian region.

It has not been possible so far to form an opinion as to the particular postglacial stage of the Great Lakes when this westward turn took place. It may have been in a narrow strip between the prairies and the coniferous forests, following the former to the north and broadening out only after reaching relatively high latitudes, in which case it could have occurred at an early postglacial stage, or it may be a more recent movement, even as late as the Nipissing stage, in which case it might have passed to the north of Lake Erie and entered Michigan by crossing the Detroit and St. Mary's rivers.

The Combined Effects.—The two migrations together may be compared to a vast U, with its base in the southern Alleghenies, one side extending as far west as the Ozarks, and the other passing northwest to Minnesota. The northern migrants have shown little tendency to move southward, especially toward the western part of their route, while the southern ones have moved steadily northward until their outposts have entered the area of the northern arm in Michigan and Wisconsin, where oak, sassafras, and sycamore occur in the same area with sugar maple, beech, and white pine. The base of the U has gradually closed over Ohio and part of Indiana, chiefly through immigration from the south. As a result there is little difference between the forests of southern Michigan and those of any part of glaciated Indiana. The valley of the Grand River in central Michigan is a well marked division line between forests of the two types, according to observations of B. E. Quick, and above it the deciduous forests are derived mostly from the northern migration.

Migration and Evolution.—The forest migration was accompanied by specific evolution also, and various species have been described from the forest region of the Middle West. In most cases their probable evolution is in doubt, from lack of careful study, but Dr. F. W. Pennell has kindly supplied certain cases among the Scrophulariaceae in which the ancestry of the species or varieties seems reasonably certain. Thus *Agalinis paupercula* of the glaciated region is considered as derived

from *A. purpurea; Aureolaria Pedicularia* (L.) Raf. (*Dasystoma Pedicularia*) has given rise to the variety *ambigens* (Fernald) of the Middle West. In other cases, the parent species, existing through the glacial period south of the ice margin, has followed both routes of migration and in so doing has become segregated into a pair of closely related forms, one of which took the southern route leading northward from the Ohio valley and the other the northern route along the Alleghenies and the Great Lakes. Thus *Trillium nivale, T. declinatum*, and *Cynoglossum virginianum* of the southern portion of the Middle West are paired with *Trillium undulatum, T. cernuum,* and *C. boreale* respectively of the northern portion.

Changes in the prairie flora took place at the same time. Distinctly western species withdrew entirely from the eastern extension or, like *Cristatella Jamesii* and others already mentioned, left relics behind in especially favorable xerophytic habitats. Relic colonies were isolated throughout the region, many of which still persist. These were subject to slow but persistent succession by the forests; many must have been obliterated, while others were greatly reduced in size.

Prairie and Boreal Relics.—The nature and location of these prairie relics and of the boreal relics in the same area may yet give a clue for the better understanding of the period and route of the northern migration of deciduous forests. There is in general a great difference in environment between forested and unforested habitats, such as a prairie and either a coniferous or a deciduous forest. Differences also exist between the two types of forest, but these are of less importance and to many species of little significance. Boreal relics, therefore, have not commonly persisted in the prairie, but remained in definite colonies. Similarly, prairie relics have been confined largely to colonies and have not persisted as scattered plants within the invading deciduous forests.[49] So, wherever the deciduous forests have succeeded the coniferous forests directly, numerous boreal species persisting to the present time bear evidence of the fact. These are of common occurrence in southeastern Michigan and indicate that the prairies were not universal there, but are rare or lacking in Illinois and Indiana, showing that the coniferous forests had disappeared before the advent of the deciduous trees from the south. Relic colonies, as has been pointed out before, remain in habitats not necessarily favorable to themselves, but unfavorable to the invaders. Consequently, prairie and boreal relics sometimes occupy the same station, into which they have been

[49] Vestal, Arthur G. Local inclusions of prairie within forest. Trans. Illinois Acad. Sci. 11: 122–126. 1918.

forced by the invasion of the deciduous forests. Such conditions are visible at the Dells of the Wisconsin, the dunes at the head of Lake Michigan, and in various places in southern and southwestern Michigan. The conclusion from both conditions is that in the western and central part of our area successions between the coniferous forests and the prairie were mostly completed before the arrival of deciduous trees, while toward the east the deciduous forests arrived before the prairies or during their advance upon the boreal associations.

Development of the Prairie-grass Formation. The prairie flora also changed considerably during this advance of the deciduous forests. Scores of species, which had been inhabitants of sand dunes, rocky soil and barrens, or the more xerophytic upland woods. migrated faster than the trees and became firmly established in the prairie associations. The only restrictions on this movement were that the plants should be herbs, dying to the ground every year and thereby escaping the effect of the arid xerothermic winter, and adapted to compete for space with grasses, which were the dominant plants of the prairies. Among these emigrants were numerous southeastern grasses which, having the same vegetative form, mingled easily with the western species and became dominant with them.

As the xerothermic period finally drew to a close, the western species were at a disadvantage. They were unable to withstand a large increase in moisture, while the species of eastern derivation could exist with a much greater rainfall. The latter accordingly became more and more abundant, until they practically dominated the prairies. In fact, the four most important grasses of the Illinois prairies, *Andropogon furcatus, A. scoparius, Sorghastrum nutans,* and *Spartina Michauxiana,* are all of eastern origin. The western species became reduced in number of individuals or restricted to extreme habitats where edaphic conditions compensated for the increased rainfall.

Here we have the origin of the flora of the eastern arm of the Prairie Province, early recognized by Pound and Clements as distinct from that of the western plains, and designated by them the prairie-grass formation. Just as the original western prairies were segregated from the arctotertiary forests by climatic differentiation, so the xerothermic period produced an analogous vegetation thousands of years later from the same stock. In the later case, however, the process was one of selective migration, rather than of extermination and evolution, and most of the southeastern species now characteristic of the prairie-grass formation still live also in the forested region of the southeastern states. Nevertheless, the movement was doubtless accompanied by evolution in many instances: *Asclepias Meadii,* a typically prairie species, seems to be

a derivative of *Asclepias amplexicaulis* of a more eastern range; a varietal evolution from *Agalinis tenuifolia* illustrates the same geographical relation, according to Dr. F. W. Pennell, and other similar cases might be cited.

The numerous ponds of the eastern arm of the Prairie Province were also formed at this time, in response to increasing rainfall in a region physiographically immature. They were of necessity colonized almost completely by species of southeastern origin, since true hydrophytes were not found in the western vegetation.

Extent of Forest Migration in the Prehistoric Period. The northern arm of the forest advance lay chiefly or wholly in a region not reached by the prairies. There is no reason to believe that it has suffered any retardation to the present time, except as caused within the past century by commercial developments in lumbering and agriculture.

The southern migration, on the other hand, was quite different in nature, due to a less favorable climate and to the character of the vegetation encountered. It has already been noted that it followed the water courses, most of which, as tributaries of the Mississippi, offer convenient highways leading from the center of forest preservation into the area of xerothermic prairies. It has also been noted that the longitudinal advance following the streams was more rapid than the lateral advance at right angles to them. The forests therefore soon assumed the form of long branching strips, following the rivers from their mouths toward their sources. Through the slow lateral advance these strips were widened and eventually became confluent across the interfluvial prairies, frequently isolating portions of the prairie in the process.

The nature of the forest advance was determined by the location of sufficient environmental change to permit the migration. Since the unfavorable environment was chiefly due to conditions of rainfall and atmospheric humidity, the advance followed the lines of topographic relief, where some shelter was offered from the drying winds and the subsurface water stood at a greater height, and the water courses where edaphic moisture compensated for low rainfall. The rolling surface of the moraines offered favorable conditions for trees of the xerarch series, and they were soon colonized by forests of oak and hickory, reaching the moraines by the intersecting streams and spreading across from one stream valley to another. On the other hand, the wide alluvial bottom lands of the larger rivers, notably the Missouri, Mississippi, and Illinois, seem to have resisted forest invasion, and on them the forests were limited to relatively narrow strips along the channel and the abandoned oxbows, alternating with strips of prairie. This condition, recorded

by numerous early observers, is so unlike our modern experience with floodplain vegetation in the Middle West that it at once stimulates inquiry into the circumstances of more recent forest development.

In a forest advance along the bluffs of a river flowing from north to south through a region of prevailingly westerly winds, the greatest protection against atmospheric conditions will be found on the western lee side of the river, rather than on the windward eastern side. Actual conditions throughout the Middle West, however, show an unexpected distribution, in that by far the largest areas of forest were originally found on the eastern side of such streams. This has been discussed in an earlier article,[50] in which the explanation was offered that the irregular distribution is due to prairie fires, which, driven before a westerly wind, have gradually destroyed much of the forests on the western side but have had little effect on those to the east of the stream. The period of great forest migration must therefore have closed with the advent of the Indian and the prairie fire.

The extent of forest advance before that time can only be approximated by a study of the present distribution of morainal forests and of the relative amounts on different sides of streams. Planimeter measurements have been made of maps showing forest distribution in two parts of Iowa and in three counties in Illinois and have given results of remarkable but not necessarily significant uniformity. In Shimek's[51] map of the Lake Okoboji region, Iowa, 26.5% only of the forests are on the west side of the lakes, and 73.5% on the east side. McGee's[29] map of northeastern Iowa shows for the Wapsipinicon River 27.9% on the west and 72.1% on the east, and for the Cedar River 29.7% on the west and 70.3% on the east. Tracings of the original land surveys of Champaign, Piatt, and Moultrie Counties, Illinois, show forests on the west side of the streams amounting to 31%, 31.6%, and 29.8%, and on the east side 67.3%, 67.4%, and 70.2% respectively. In Champaign County 1.7% and in Piatt County 1% of the forest area is in isolated groves apart from any river system. If we may assume that forest was originally developed equally on both sides of the streams, the total area would be increased by amounts ranging from 36% of the present area in Piatt County to 44% along the Wapsipinicon River. The lakes of the Okoboji region would have additional forest on the west side amounting to 47% of the present total, and if they were carried completely around the lakes the increase would be still greater.

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[50] Gleason, H. A. The relation of forest distribution and prairie fires in the Middle West. Torreya 13: 173–181. 1913.

[51] Shimek, B. The plant geography of the Lake Okoboji region. Bull. State Univ. Iowa. Bulletins from the laboratories of natural history 72. 1915.

The extent of migration up the streams beyond the present limit of forest can be considered with less accuracy. The original land surveys frequently show small areas of forest isolated from the main body along the head waters of a stream. Also, the upstream end of the forest belts is regularly wide and blunt. Modern observation shows that in the same area establishment of new forest is rapid as far upstream as there is a differentiation of upland, bluff, and floodplain. If the interruped belts were made continuous and were extended upstream according to the topography, there appears to be room in Champaign County for at least 28 more miles of forest belt, comprising probably 14 square miles. There is also evidence that the moraines were forested wholly or in part in prehistoric time. Fragments of the forests still persist in sheltered places in Champaign County, and well developed morainal forests occupy considerable areas of McLean County. In Champaign County, about 50 square miles of land is morainal and may have been forested.

The land survey maps indicate 44,846 acres of forest in Champaign County, and this figure is apparently somewhat too small, since the surveyors frequently referred to trees up to two feet in diameter standing on land designated on the map as prairie. Increasing this amount by 64 square miles makes a possible total of nearly 86,000 acres of prehistoric forests, almost twice the present extent, and increases the proportion of forest, from 7.1% to 13.5% of the total area. While the accuracy of this estimate can not be proved, we may safely conclude that the forested area was at one time greatly larger than its present extent through Illinois and Iowa, and doubtless also through the prairie region of Wisconsin and Indiana.

Second Period of Prairie Dominance. The advance of the forest would in time have given a continuous forest covering to the Middle West, except on those limited habitats where tree growth is impossible for edaphic reasons. The forest would have extended west to the climatic limit of tree growth and tongues would have projected beyond the principal area along the habitats where special environmental conditions compensated for the unfavorable climate. This advance came to a sudden conclusion with the arrival of the American Indian and the consequent introduction of prairie fires. This stage in the history of the Middle West has been discussed in an earlier paper[50] and needs only brief recapitulation here.

Prairie fires were set annually by the Indians in the autumn months to drive game from the open prairies into the forest, where it was more easily stalked. Sweeping eastward before the prevailingly westerly winds of that season, the fires destroyed seedling trees at the west margin of the forest, preventing further advance in that direction. It is doubt-

ful if they penetrated far into the forest, but by destroying the undergrowth and killing the more susceptible species, they gradually reduced the forest to the open parklike condition known as oak openings. Here the herbaceous vegetation was composed largely of prairie grasses, which furnished additional material for fires and led to the annual extension of the prairie through the eventual death of the remaining trees. The forest was thus slowly pushed back to the river bluffs, where the greater topographic diversity favored its persistence, or, where the bluffs were low and with gradual slopes, was completely destroyed on the west side of the streams. Fires even crossed the smaller streams, attacked the forests of the eastern side, and by burning through them isolated areas of forest toward the headwaters of the stream from the main body below. This condition is shown in several places on the original land surveys of central Illinois, and examination of them indicates that the separation was always in places of low relief, leaving forests isolated where the bluffs were steeper or higher.

On the eastern side of the forest, protected against fires driven by the prevailing winds, encroachment by the prairie was less rapid and doubtless in many cases negligible. It is probable that the forest advance was completely stopped in some places, but may have continued slowly in others.

Along the moraines, which are generally characterized by a gently rolling topography, the forests were destroyed completely, except in those few favored situations where ponds or swamps on the west side acted as an effective barrier to the fires.

Another effect of prairie fires was the production of the so-called barrens, areas characterized by a sparse growth of "scrub" oak (apparently *Quercus velutina* in most cases), hazel, and wild plum. The exact cause of the barrens is unknown, but descriptions from early literature and accounts of personal observers in Illinois, Indiana, and Iowa agree that these three species of plants were the principal, if not the only, woody species present, and that they seldom exceeded four or five feet in height. They seem to represent a late stage in the degeneration of the forest, where seedlings were established and the young plants burned to the ground frequently without completely destroying the root system. This developed further each year, reached a large size, and sent up sprouts annually which persisted a year or two longer before the next fire again killed them to the ground.

During this same period, a few new isolated groves were established on the prairies, but always in areas well protected from the fires. Two such have been examined in Champaign County, Illinois, are mentioned before in this paper, and described in more detail elsewhere[50]. They

are composed exclusively of mobile species and have been in existence such a short time that they have not yet changed the nature of the prairie soil[52].

Second Period of Forest Advance.— Settlement of the forested regions of the Middle West began about the opening of the nineteenth century, progressed steadily westward, and reached the Missouri River in fifty years. Actual settlement of the prairies was long avoided, vast areas were still untouched at the time of the Civil War, and prairie fires did not cease being a menace in parts of Illinois until 1860 and in Iowa until somewhat later. As soon as fires ceased, the advance of the forest was renewed, and at a rate probably more rapid than the original, since considerable improvement of climate may have taken place since the first advance was stopped by fires.

Early literature contains many accounts of this spread of the forested area, which was rapid enough to attract the attention of travellers. It seems to have progressed in several different ways. The lateral advance of the forest at right angles to the streams and the longitudinal advance along the streams continued as before. Willows, cottonwoods, and some hydrophytic shrubs moved rapidly up the rivers and creeks, and were followed by elms, maples, and ashes. Thirty years after the first prairie settlements were made in Macon and Moultrie counties, Illinois, these fringing forests had extended one or two miles up the smaller streams. Isolated colonies of mobile species, especially willow, *Salix humilis,* and wild plum, *Prunus americana,* were established well out on the prairie, grew into thickets, and frequently received further additions of forest species, carried in by the birds which visited them or by wind. Large areas of barrens were converted into forest as by magic, when the fires that had maintained them were stopped and the oak sprouts became trees.

The total afforestation during this period was considerable and in some cases almost unbelievable, and may best be indicated by a few examples. Thus the driftless area of northwestern Illinois and southwestern Wisconsin, which now gives the impression of having been heavily forested, was 80-90% prairie a century ago,[53] and was described by Keating[54] as presenting "the waved appearance of a somewhat ruffled

[52] Hopkins, C. G., J. G. Mosier, E. Van Alstine, & F. W. Garrett. Champaign County soils. Ill. Agr. Exp. Sta. Soil Report 18. 1918.

[53] Schockel, Bernard H. History of development of Jo Daviess County. Illinois State Geol. Surv. Bull. 26. 1916.

[54] Keating, William H. Narrative of an expedition to the source of St. Peter's River . . . performed in the year 1823 . . . under the command of Stephen H. Long. Philadelphia, 1824.

ocean; it is covered with a dry short grass," while the higher knobs, now concealed by the forest, rose from the midst of the prairie and were visible thirty miles. A little later we find farmers near St. Louis complaining that the rapid growth of trees had seriously restricted the natural pastures.[55] The Mississippi and Illinois rivers at that time had long strips of prairie in their floodplains, which are now completely forested, except where under cultivation. The dune region at the head of Lake Michigan, which is now well forested with oak, was then "treeless, except for a few stunted pines." Forested areas in Indiana were developed, within the memory of men now living, from barrens over which a man on horseback had been visible for six miles (personal communication from Mr. C. C. Deam). The rapid development of forests on the sand dunes of the Illinois River has been noted elsewhere.[56]

This great forest advance of the nineteenth century proceeded by ordinary successional processes and affected hundreds of square miles. It ceased only with the complete occupation of the prairie land for agriculture. Since then, that is, during the last 50 years, forest succession has been limited to sand dunes, roadsides, and railway lines. Every roadside in the Middle West is a potential forest and would speedily become so in fact except for constant effort in keeping the thickets and young trees cut down.

Coastal Flora of the Great Lakes.— The extensive sandy beaches of the Great Lakes are characterized by a number of species which do not occur or are rare elsewhere in the Middle West. The geographical origin of many of these species is indicated by their distribution elsewhere or by the range of their nearest relatives. Thus *Iris lacustris* is closely related to *Iris cristata; Solidago Houghtonii* to *S. Riddellii* and *S. ohioensis,* and both were probably derived by immigration from the south, accompanied by specific evolution. *Cirsium Pitcheri* may have a similar origin. *Corispermum hyssopifolium,* for similar reasons, appears to have entered the region from the west. Besides these, there is a considerable group of species which are distributed along the northern shores of the Atlantic, sometimes in Europe as well as America, are not ordinarily found inland, but appear along the shore of the Great Lakes. This group includes *Ammophila arenaria, Elymus arenarius, Juncus balticus, Halerpestes Cymbalaria, Cakile edentula, Prunus pumila, Lathyrus maritimus, Chamaesyce polygonifolia, Hud-*

[55] Peck, J. M. A gazetteer of Illinois. Philadelphia, 1837.

[56] Gleason, H. A. The vegetation of the inland sand deposits of Illinois. Bull. Illinois State Lab. Nat. Hist. 9: 21–174. 1910.

sonia tomentosa, and *Tanacetum huronense*. Two other species, *Salix syrticola* and *Solidago Gillmani*, are endemic to the Great Lakes, but the distribution of their nearest relatives indicates that they are of the same ultimate geographical origin.

The most plausible explanation for the occurrence of these species so far inland from their maritime range is that they migrated along the shores of the Champlain Sea during the Algonkian or Nipissing stages of the Great Lakes, and entered the lake region along the Kirkfield or North Bay outlets.[23] This explanation agrees with the present center of abundance of the lake shore species near the north end of Lake Huron and, since the ice fields were not far away during this period, with their prevailingly northern maritime distribution.*

SUMMARY OF PART IV AND CONCLUSION.— 1. The principal vegetational and floristic elements of the Middle West were differentiated during the Tertiary Period and have continuously maintained their present relative position.

2. Each glacial advance has induced extensive migrations toward the south and west, but in them the coniferous and arctic floras have been greatly narrowed and the deciduous forests have lived uninterruptedly in the Ohio valley.

3. Extensive readjustments of distribution have taken place in each interglacial stage. During the Sangamon, most or all of the Middle West was probably occupied by deciduous forests.

4. Climate in the Middle West beyond the Wisconsin glaciation was semi-arid during the time of maximum ice advance, thereby restricting the boreal floras greatly toward the west.

5. A xerothermic period followed the retreat of the Wisconsin ice, and caused the eastward migration of prairies as far as Ohio, succeeding the coniferous forests as the latter migrated north.

6. A gradual increase in rainfall was accompanied by a westward migration of deciduous forests. This was composed of two elements, one moving from the Ohio valley and one from the Allegheny Mountains. At the close of this period, forests occupied a much greater proportion of the Middle West than at present.

7. With the arrival of the Indian and prairie fires, prairies again began to encroach on the forests and reduced the forested area to its condition at the beginning of the last century.

8. During the nineteenth century extensive afforestation took place, continuing until the land was placed under cultivation.

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* Since this paper went to press, D. C. Peattie has discussed this subject in more detail in Rhodora 24: 57-70, 80-88. 1922.

The writer has no doubt that further study of the problem of glacial and postglacial vegetational history, based on additional facts of modern distribution, on better knowledge of plant migration and the ecological requirements of species, and on new evidence from fossils, and carried on by investigators with different viewpoints and different personal experiences, will lead to many important modifications of the outline here presented. The field is large, almost untouched, and of compelling interest, and it is hoped that it will attract the attention of students not only in the region here discussed, but elsewhere through the country as well.

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SHORE CHANGES AT CAPE HATTERAS

G. T. RUDE

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INTRODUCTION.— Since volumes have been written on shore processes, it is evident that in a limited discussion little is to be gained by a general and purely theoretical consideration of the subject, and it has been elected, therefore, in the preparation of this short paper to take a particular locality and attempt to show by quantitative data a correlation between shoreline changes and local storm data. I am indebted to the officials of the U. S. Weather Bureau for their courtesy in allowing me the privilege of consulting original records from their meteorological station at Cape Hatteras for the period — 1875 to the present time.

Since the results of the surveys which are obtainable for the purpose of showing the changes in the shoreline of Cape Hatteras at different periods somewhat antedate available meteorological data, final conclusions to the second decimal place are not to be expected, and it is hoped that this discussion will be considered as the beginning only of a collection of quantitative data, which may in time be supplemented, tending finally toward conclusive results along these lines.

As is the case in practically all research work along oceanographic, geologic, geophysical and many other lines, there is a dearth of data of a quantitative nature over even the relatively short period covered by this study, and it has been necessary to employ mean values over a large part of the period.

CURRENT AND WAVE ACTION.— While currents undoubtedly play a large part in shoreline changes, they may be considered only the transporting agents and not the cause of the changes, the impact and backwash of storm waves being the direct causes, furnishing the material to wind-driven currents, not tidal currents. (The writer is not unmindful of a type of currents in waves and in wave action itself, but these, too, are relegated to subordinate positions as direct agents; the power in

wave impact being considered the principal agent.) In general, coastal tidal currents except at the immediate entrances to estuaries are of small velocity—seldom exceeding two or three tenths of a knot,—while alongshore wind-driven currents may attain a velocity at times of one to one and a half knots.

Of course, the conditions outlined above are for the exposed coasts and not for rivers or straits. In these cases we have, in the former, freshet currents cutting at the outer bends and depositing the material in the sluggish waters in the inner bends and on the deltas; in the latter we have action of a current not strictly tidal. In the East River, for example, strong currents have swept the channel to bedrock, depositing the material in the quieter bays and coves along its banks. These currents, however, are not tidal currents of the purely rotary or progressive type, but rather are hydraulic currents due to difference in head between the waters of Long Island Sound and New York Bay.

It therefore appears safe to assert that, in general, impact of wave action is the prime factor in shoreline changes on the open coast and wind-driven currents the secondary factor or transporting agent.

For this particular study the Atlantic coast has been taken in the immediate vicinity of Cape Hatteras. Attention is called to the arc of exposure to the Atlantic storms—from north practically to southwest by way of east. While length of fetch is accepted as a factor in shore changes, it does not enter into this discussion, since the fetch over this arc is of sufficient length to preclude it from the consideration.

The Wind and Storm Data.— In arranging the prevailing wind data, including storm winds, (Table A), the mean yearly wind movement has been taken from the original meteorological records of the Cape Hatteras Weather Bureau station for the past 50 years for each cardinal and inter-cardinal point and resultants secured which, in addition to the tabulated values in Table A for 10 year periods, are shown graphically at the top in Fig. 1 by the arrows, their lengths representing the relative strengths of the different components, the solid arrows through the arc of exposure and the skeleton arrows through the protected or shore arc. The marked southerly component may be noted; this fact will *partly* explain the total southerly progression of the shoreline on the extreme point at Cape Hatteras as shown in Figure 1. Unfortunately, no meteorological data are available prior to 1875.

The arrows near the center in Figure 1 represent graphically the resultants of the *storm winds* for the 21 year period from 1900 to 1920. Here, too unfortunately, the storm wind data extend back only over a short period — to the year 1900. These storm wind data are also tabulated in Table C.

In arranging the storm data the United States Weather Bureau's

definition of a storm wind has been accepted. This velocity is now taken at 40 miles per hour; that is, this velocity is attained each hour and maintained for at least five minutes, and storm warning signals are displayed for winds of that velocity. Prior to 1906, it was 33 miles per hour; therefore for the purposes of this discussion the latter figure was taken through the entire period in order to make the two periods comparable.

The arrows, then, and the tabulated values in Table C show the resultant forces of such storm winds for a period of 21 years, the length of the arrows and the numbers indicating the relative strengths of resultants, the skeleton arrows in the protected arc and the solid in the exposed arc, as in the case of the prevailing wind arrows.

In summing the storm-wind velocity-hours for each cardinal and inter-cardinal point for this period, only those hours were taken which were of a 33-mile velocity or over, and then only for days during which the total wind movement aggregated 600 wind-velocity-mile hours or more; that is, a squall of just a few hours duration was neglected for the reason that no sizeable sea is likely to be created by such a squall. Since the total wind movement for different days varies from about 100 velocity-mile hours to about 1200, 600 was taken as the minimum total wind movement which would best define a storm day. Instead of summing the absolute velocity values for the different hours, in the case of storm winds, the number of storm hours were summed for each cardinal and inter-cardinal point.

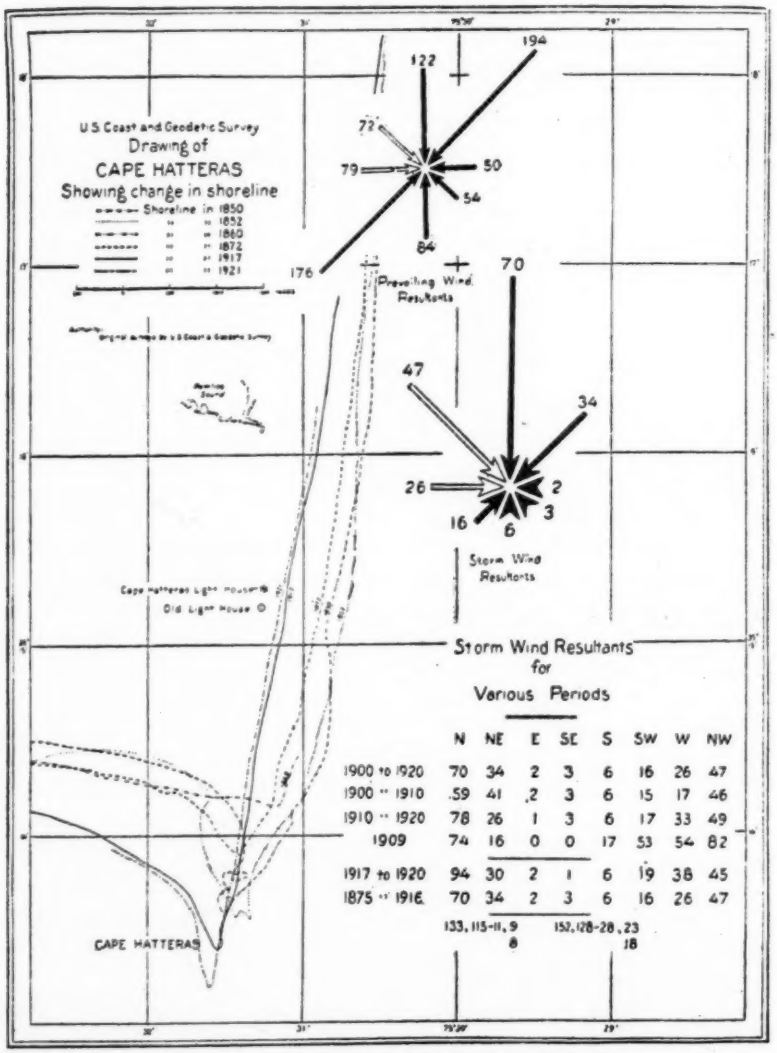
In Table B are shown the resultants for each cardinal and inter-cardinal point of the storm winds for different periods. For comparison the period 1900 to 1920 has been separated into two periods — 1900 to 1910 and 1910 to 1920. Considering the variability of storms it is remarkable how closely the resultants agree when taken over long periods. The information conveyed by the quantitative data in Table B would tend to indicate that the force exerted on this coast line by storm wind-waves is not the variable[1] factor ascribed to it, nor that the prevailing winds are offshore and the greater storms from the south and west[2].

Resultants for the year 1909 are shown in order to call attention to the striking variation from the mean of the values for the northeast and southwest — 16 to 53, the only year over the whole period in which the southwest resultant equalled or even approached the value of the northeast, and this year it will be seen that it has over three times the strength of the northeast component.

Quantitative Measurements of Changes of Shore Form.—Figure 1 shows the shore changes at Cape Hatteras during the past 71 years, as secured from surveys made in 1850, 1852, 1860, 1872, 1917, and

[1] Haupt, p. 149, Proc. Am. Phil. Soc. XXVI, 1889.
[2] Haupt, p. 155, Proc. Am. Phil. Soc. XXVI, 1889.

1921. Along the straight shoreline where there has been a consistent recession apparently during the entire period, the average movement each year from 1917 to 1921 has been *11 yards*. A comparison of the storm wind resultants shown in Table B for this period over the arc of exposure from north to south with those of period 1875 to 1917 is as



	N	NE	E	SE	S	SW	W	NW
1900 to 1920	70	34	2	3	6	16	26	47
1900 " 1910	59	41	2	3	6	15	17	46
1910 " 1920	78	26	1	3	6	17	33	49
1909	74	16	0	0	17	53	54	82
1917 to 1920	94	30	2	1	6	19	38	45
1875 " 1916	70	34	2	3	6	16	26	47

133, 115-11, 9 8 152, 128-28, 23 18

FIG. 1.—Map of changes at Cape Hatteras

TABLE A.

PREVAILING WIND MOVEMENT, CAPE HATTERAS METEOROLOGICAL STATION.
Ten Year Averages for the Period 1875 to 1920.

Period	Average Yearly Total Wind Movement	Average relative frequency of winds from							
	Mile hours	N.	N. E.	E.	S. E.	S.	S. W.	W.	N.W.
1875–1884	120390	95	340	62	95	87	224	76	81
1885–1894	116295	167	160	52	47	121	155	95	80
1895–1904	122474	137	153	43	46	79	144	86	66
1905–1914	128216	94	166	44	43	60	189	69	72
*1915–1920	129380	118	149	52	41	72	167	69	63
	Means	122	194	50	54	84	176	79	72

* 4 years, record for 1918–19 in use, not available.

TABLE B.

STORM WIND RESULTANTS FOR DIFFERENT PERIODS.

Period	Average number of Storm Hours with winds from							
	N.	N. E.	E.	S. E.	S.	S. W.	W.	N. W.
1900 to 1920	70	34	2	3	6	16	26	47
1900 to 1910	59	41	2	3	6	15	17	46
1910 to 1920	78	26	1	3	6	17	33	49
1909	74	16	0	0	17	53	54	82
1917 to 1920	94	30	2	1	6	19	38	45
*1875 to 1916	70	34	2	3	6	16	26	47

* Using mean values prior to 1900.

TABLE C.

YEARLY STORM WIND RESULTANTS FOR THE PERIOD. 1900 to 1920.

Year	Number of storm hours with winds from							
	N.	N. E.	E.	S. E.	S.	S. W.	W.	N. W.
1900	47	0	1	7	3	13	43	36
1901	69	1	0	0	4	1	18	70
1902	28	29	2	0	2	9	7	20
1903	128	42	4	7	1	34	5	24
1904	10	6	3	0	1	12	13	12
1905	69	38	0	2	9	2	16	32
1906	121	103	4	0	9	1	0	13
1907	31	108	0	7	3	8	8	67
1908	37	85	11	6	15	20	21	86
1909	74	16	0	0	17	53	54	82
1910	31	28	0	0	2	10	2	64
1911	41	5	0	0	3	12	12	44
1912	66	35	0	0	15	21	37	73
1913	33	23	3	7	10	25	17	38
1914	119	14	0	15	2	16	47	39
1915	70	47	3	5	6	11	75	33
1916	123	20	0	0	1	13	21	66
1917	96	32	3	3	10	16	65	74
1918	98	26	6	2	6	37	15	29
1919	86	15	0	0	0	0	21	27
1920	96	45	0	0	9	22	53	50
Means	70	34	2	3	6	16	26	47

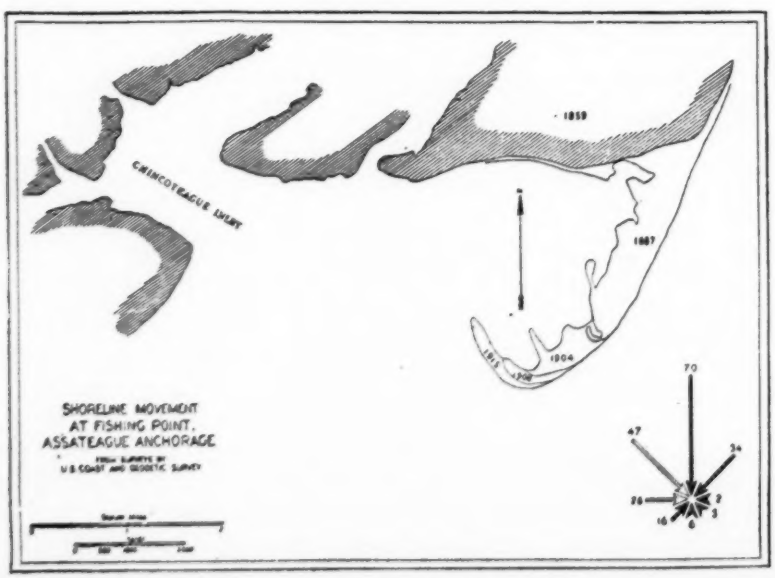


FIG. 2.—Shoreline movement as Assateague Anchorage

133 is to *115,* using actual values back to 1900 and mean values prior to that year, for the reason that no data are available previous to that time. Introducing these factors and the average movement of *11 yards* for the period 1917 to 1921, into a proportion gives a computed movement of *9 yards* each year for the earlier period, while the actual mean movement as measured every half mile along the coast is *8 yards* each year for that period.

Now, during the period between two early surveys at Cape Hatteras (1850 to 1860), a recession of the shoreline on the point occurred (Fig. 1), where there has since been a steady progression at that point. Unfortunately the recession at the extreme point occurred prior to the availability of meteorological records, but this recession may be explained by reference to the data for the year 1909 which, as shown in Table C, has a strong northerly resultant, and the recession may have been due to several such years during that periol for which no records are available.

For changes in the shoreline on the south side of the point the storm winds over the whole arc of exposure have been considered. A comparison of these resultants for the period, 1917 to 1920, with the earlier period, 1875 to 1916, are as *152* is to *128,* and the average yearly shoreline change has been *28 yards* each year for the later period. Introducing these factors and the *28 yards* into a proportion gives a computed change on the point for the earlier period of *23 yards* per year, while the actual change has been *18 yards.*

As a matter of interest, changes at Assateague Anchorage, Va., are shown in Fig. 2 for the period 1859 to 1915, as secured from the results of surveys made in 1859, 1887, 1904, 1908 and 1915. Here we have a marked southerly progression of the point, making an excellent harbor of refuge where half a century ago the broad Atlantic rolled in. In the lower right, Fig. 2, are also shown graphically the storm wind resultants obtained at the Cape Hatteras Meteorological Station and while they may not apply exactly to this locality, they undoubtedly indicate the general storm conditions along this stretch of coast.

It is questionable whether further study even will allow of quantitative results in the case of Assateague Anchorage; for the reason that conditions are constantly changing as the point builds to the southward, and it may be that many of the factors cannot be evaluated.

When the point was in the 1859 position the entrance into Chincoteague Inlet was relatively wide and therefore the tidal and storm-driven currents entering the inlet comparatively weak. As the point builds to the southward this entrance is gradually narrowing and these currents therefore becoming stronger at the entrance, causing the point to curve in more sharply at each survey. An inspection of

Figure 2 will show indications of the remains of the earlier curves. It probably may be safely predicted that in another 50 years or so the point which was shown to be curving sharply to the northward in the survey of 1915 will have closed across to the other shore and Assateague Anchorage filled in, the whole point then taking somewhat the same form as Cape May at the entrance to the Delaware, which may likely have been built up as this point is building. Cape May has ceased to build now that the currents entering the bay have become too strong for the material to settle and consequently it passes on into and up the bay to help build up the bars for which that bay is noted.

A similar condition at Assateague makes it difficult to evaluate all factors. If the material brought along the coast by wave and current action were deposited at the point, as a large part of it was in 1859, it would be a fairly simple matter; but much of this material, and in increasing amounts, is swept on into Chincoteague Inlet by currents entering past this point.

Further study of a quantitative nature at the entrance to estuaries on the open coast, taking into account the degree of narrowing at the entrance and actual current observations, may lead to interesting conclusions. This will require, however, more extensive meteorological and current data than now available.

Effects of Tidal Action.—The changes in the shoreline of Cape Hatteras have been treated by some investigators in a manner somewhat different from that attempted by the present writer. It is thought undue importance has been attributed to "On- and offshore tidal action," "Flood tide action," and "Back-set eddies" in the building or changing of this shoreline. The material attributed by some authors[3] as coming from seaward for deposit on the cape has undoubtedly been transferred from the shoreline north of the cape by storm wave action and alongshore wind-driven currents—coming from seaward only in that it swings shoreward into the comparatively quiet waters of the bight south of the cape after passing the point during northerly storms which prevail along this coast. The recession of the shoreline north of the cape is indicative of the source of this material which is added to the cape on its south side.

Regarding "On- and offshore tidal action" and "Flood tide action,"[4] sand will be driven along the bottom if the velocity there be 0.4 knot; fine gravel, if about 1 knot; shingle, about 1 inch in diameter, if 2.5 knots; angular stones, about 1½ inches in diameter, if 3.5 knots[5].

[3] Gulliver, Proc. Am. Acad. A. S. XXXIV, 1899.
[4] Haupt, Proc. Am. Phil. Soc., XXVI, 1889.
[5] Harris, Manual of Tides, 1894–1907.

From observations made at Diamond Shoals Light vessel, located about 25 miles off Cape Hatteras the *tidal* current is about 0.1 knot, and at Frying Pan Shoals Light vessel, located about 20 miles off Cape Fear, the *tidal* current is about 0.4 knot. From current observations made over a long period on the light vessels along the coast it has been found that currents generated by *winds* attain a velocity in knots per hour equal to 1½ per cent of the wind velocity in miles per hour in a direction about 20° to the right of the wind direction. For example, a northeast storm with a wind velocity of 75 miles per hour will create on the Atlantic coast a current of about 1.2 knots per hour setting about W.S.W. It will be seen therefore that not only are *storm winds* on the exposed coast almost as invariable as *tidal* action but also that the currents they generate are far more effective in the movement of ocean floor material than the weaker tidal currents.

THE SIGNIFICANT FACTORS.—In conclusion, we may consider briefly "Back-set eddies."[6] It is very probable that, if such eddies from the Gulf Stream did exist, they would have explained very nicely the formation of this cuspate cape; but current observations over the continental shelf tend to disprove this hypothesis. Instead of assuming a nonexistent northeast—southwest *eddy* current effect, we find the prevailing *storm winds* produce a prevailing southwest set. This set changes, however, at times when storms come from other quarters, for they, too, carry their current during the time they are blowing.

The writer during two winters, 1915-16 and 1916-17, was engaged on off-shore hydrographic work from the Carolinas well down the Florida coast and from the shore out to the Gulf Stream, involving the securing of current observations over this area. An analysis of the current observations on the continental shelf show in all cases the rotary tidal current, and also a set with the local wind prevailing at the time of observation. In cases where observations were made at the same anchorage at different times and under different wind conditions the set of the current agreed with the wind blowing at the time. If the direction of the wind at an anchorage was opposite to that at the time of previous observations the set of the current was opposite to the set of the current at the previous time.

[6] Abbe, Proc. Bost. Soc. Nat. Hist., XXVI, 1895

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THE BARRIER REEF OF TAGULA, NEW GUINEA

W. M. DAVIS

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SUMMARY.—Tagula, the largest member of the Louisiade archipelago east of New Guinea, is a mountainous island, 30 miles long by nine wide, and 2645 feet in height. Like its neighbors, it is composed of deformed and greatly eroded schists and slates; all the shore lines are embayed; hence the islands may be regarded as parts of a long mountain range of similar structure in northern New Guinea, which have been isolated by strong subsidence. Tagula stands in the eastern part of a vast lagoon enclosed by a great barrier reef, measuring 112 by 30 miles; the western part of the lagoon is divided into a northern and a southern compartment by a chain of small satellite islands; the lagoon floor in each compartment is a smooth plain with maximum depths of 49 and 46 fathoms in the broadest parts. The narrower parts of the lagoon are shallower, evidently because a given quantity of inwashed reef detritus has there caused a greater aggradation. An exceptional feature is the occurrence of 26 minute islets, mostly from 40 to 150 feet high, probably residuals of a former elevated reef, in the northwestern half of the present reef. Two smaller barrier reefs and a few small atolls with shallower lagoons are found near by. The less depth of these lagoons, like that of the narrower parts of the Tagula lagoon, is undoubtedly due to the greater efficiency of aggradation by inwashed reef detritus in lagoons of small area. Not far to the north,

Misima, a mountainous island, measuring 22 by 10 miles, with a height of 3500 feet, has no barrier reef but is terraced by several uncomformable elevated reefs; hence in addition to the general subsidence of the region as indicated by the isolation of its parts, this island has suffered upheaval in recent time.

The smooth floor of the Tagula lagoon cannot be due to the presence beneath it of a smooth platform abraded during the lower stands of the ocean in the Glacial period, because the survival of the minute islands in the barrier reef and the absence of spur-end cliffs on the larger islands prove that no extensive abrasion, either by the normal ocean or by the lowered ocean of the Glacial period, has taken place. Hence the islands must have been protected by living reefs all through

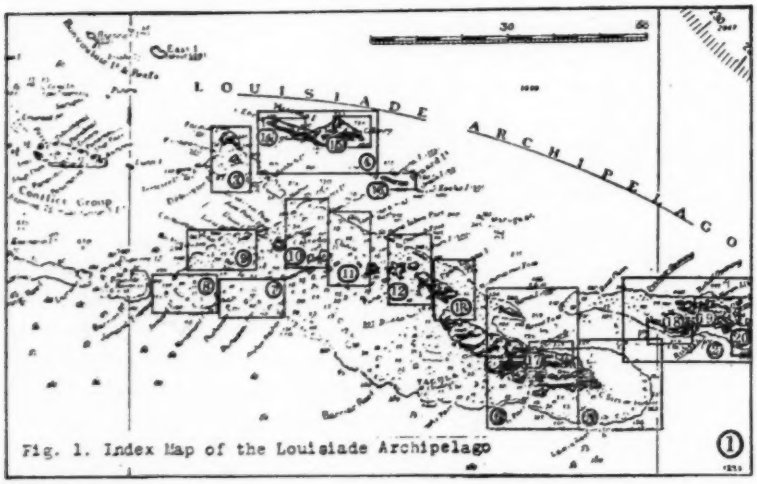

Fig. 1. Index Map of the Louisiade Archipelago

the Glacial period. The depths of the Louisiade lagoons are essentially accordant with the depths of lagoons of similar size in the open Pacific. Hence as the reefs in this region of demonstrated subsidence appear to have been formed by upgrowth from island foundations of uneven form, and as the lagoons within the reefs appear to have been given smooth floors of ordinary depths by the inwash of reef detritus without the aid of abraded sub-lagoon platforms, it follows that similar processes may have produced the similar reefs and lagoon floors of the open Pacific; and, further, that stability of reef foundations and the abrasion of sub-lagoon platforms at a standard depth, as assumed in the Glacial-control theory of coral reefs, are no more essential in the open Pacific than in the Louisiade archipelago. In other words, the Louisiade reefs and lagoons give strong support to Darwin's theory of reef upgrowth

and lagoon aggradation on subsiding foundations; and thus warrant the acceptance of that theory for many other reefs and lagoons—and especially for atolls—in regions where evidence as to the stability or instability of foundations and as to action or inaction of low-level abrasion in the Glacial period is either less decisive or wanting.

Charted Facts Concerning Tagula and Its Reef.—This paper is based upon a study of published maps and charts, of sketches, and a few of geological notes made by scientific observers who have visited the island. The Louisiade archipelago as a whole is shown on a small scale in Figure 1, which reproduces a part of Hydrographic Office

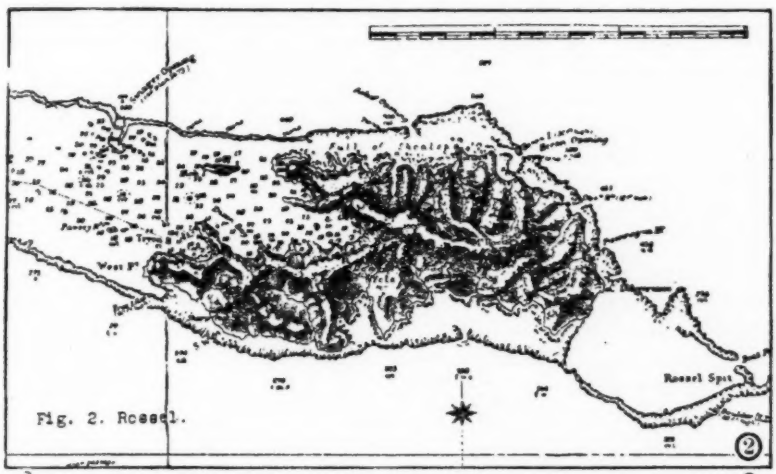

Fig. 2. Rossel.

Chart 2942; the outline of the islands and reefs has been strengthened to make them clear. British Admiralty Chart 2124 includes all the islands of the group on a much larger scale, about 1:300,000. The largest island is Tagula, sometimes called Sudest. A central segment of it is shown in Figure 6. Rossel, Figure 2, on the east, and Panniet or Deboyne, Figure 3, on the northwest, are smaller. Each of these three islands is associated with a barrier reef. Misima or St Aignan, Figure 4, lies farther north and is peculiar in descending rapidly into deep water, without either fringing or barrier reefs; but it bears elevated fringing reefs. B. A. Chart 1477, on a still larger scale of 1:133,000, includes the northwestern part of Tagula and of its great barrier reef, as well as Deboyne and Misima on the north. Several rectangles from this beautiful chart are here produced in Figures 7 to 13. Another B. A. chart, 1473, shows Rossel on a similarly large scale; Figures 17 to 20 are taken from it. An immense number of

carefully determined facts regarding the pattern of shore lines, the outline of reefs, and the depths of lagoons are thus recorded. The locations of all the excerpts from the several charts are shown by correspondingly numbered rectangles in Figure 1. The larger rectangles are from chart 2124; the others are from charts 1477 and 1473 of larger scale. Two additional figures, 21 and 22, are from H. O. Chart 2961 on the same scale as B. A. 2124; they show parts of the northern coast of New Guinea lying to the west of the area of Figure 1. A number of figures from these charts are here included because the features under discussion are unusual and because large-scale charts of such features are not generally accessible.

The island of Tagula is 30 nautical miles long from east-southeast to west-northwest—or from east to west, as this slightly oblique trend will be hereafter stated; it is eight or nine miles wide, and has 10 summits from 1330 to 2645 feet in altitude. The island is overlapped on the north by a series of satellite islands, known as the Calvados chain, shown in Figures 10 to 13; the chain begins about seven miles north of the middle of the main island, as shown in Figure 6, and extends 70 miles to the west, with more than a score of members, the largest having a length of 11 miles and a height of 1110 feet. The main island and its satellites are all charted as having irregular and non-clift shores, in which the mountain spurs advance as sloping points and the valleys retreat in open embayments. The shores are in part bordered by fringing reefs up to a mile or more in width. In view of so great a fringing-reef width, it is probable that bay-head deltas have a considerable development, and that but for their presence the shore-line embayments would extend a mile or more inland back of their charted heads, making the island shoreline much more irregular than it is now.

Tagula and its satellite chain are surrrounded by an extraordinary barrier reef of irregular oval outline, having diameters of 112 miles east-west, and 30 miles north-south. The coral seas contain no finer example of an encircling reef. It is strongly developed around the eastern curve of its great circuit (Fig. 5), where the reef flat attains a width of one or two miles, and where it is interrupted by only four passes in a distance of 110 miles. For eight miles along the mid-north coast of Tagula the barrier joins the island shore as a fringe, half a mile wide, as shown in Figures 6 and 17; here a steep descent is made to 200 fathoms or more in a mile from the island shore. North of the eastern end of the Calvados chain, the slightly submerged reef flat is still a formidable barrier, a mile or more in width, as shown in Figures 12 and 13. For a distance of 20 miles in the western part of the southern half of the oval, the reef is charted as a "sunken barrier" at depths of from three to eight fathoms, shown in part in Figure 7.

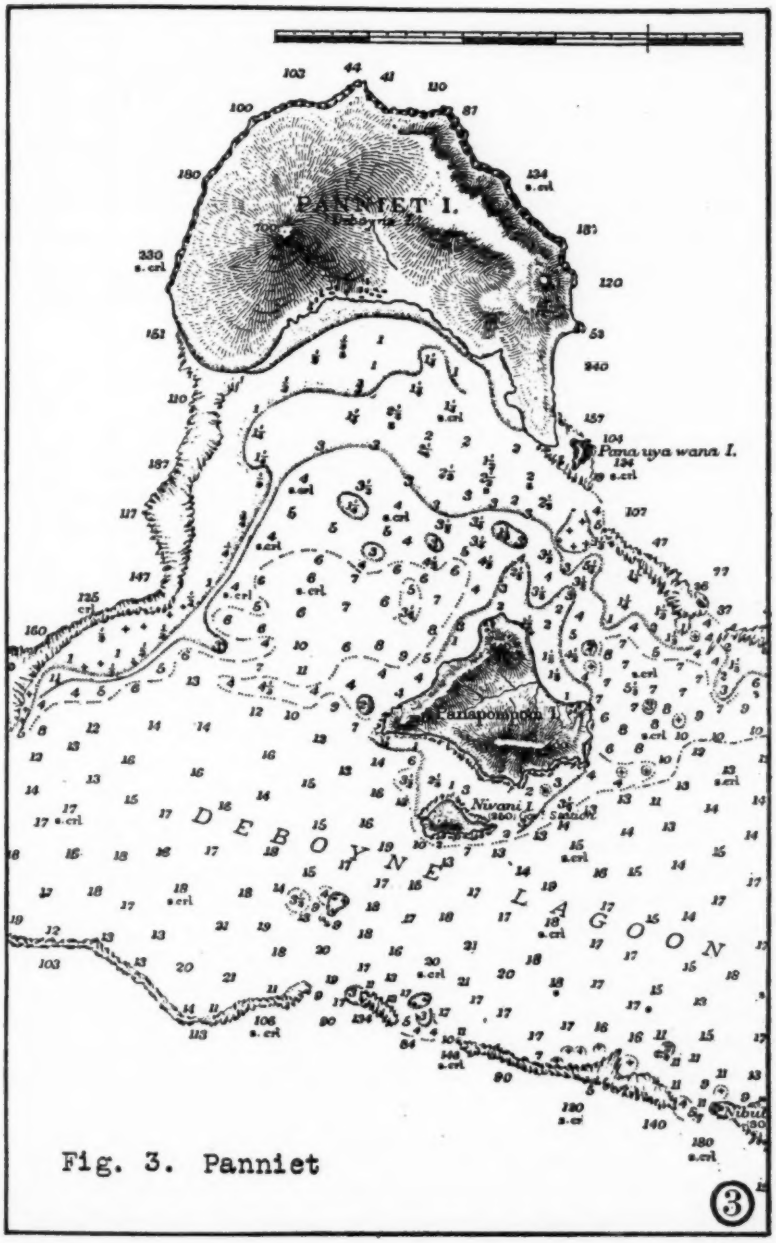

Fig. 3. Panniet

Around the northwestern part of its circuit the reef is strikingly discontinuous; it there consists in part of small patches, but more commonly of atoll-like loops and rings, 36 in number and from one to five miles in diameter, enclosing little lagoons from 10 to 17 fathoms in depth. Some of the loops are long and narrow; one of this kind stands at the northern turn of the great barrier (Fig. 10); others are pronouncedly crescentic, with the horns pointing into the great lagoon (Fig. 9). The patches, loops and rings are separated by passages from 13 to 35 fathoms deep and from one-quarter to three miles wide, the widest being in the southwestern arc of the reef circuit (Fig. 8). The passages between the crescentic loops are peculiarly long and narrow, like those on either side of the Utian loop (Fig. 9).

Several of the reef loops include small or minute islets, 26 in all, ranging in height from 40 to 530 feet. The largest, Utian (Fig. 9), in the western part of the barrier is 1½ miles across, and 460 feet high; the longest, Sabari (Fig. 12), stands in an imperfect loop where the looping of the reef first begins, northwest of Tagula; it is four miles in length and 180 feet in height. The higher islets have strong slopes, but with very few exceptions they do not appear to be clift. These islets will be here called outposts. As elements of a barrier reef, both the outposts and the reef loops from which they rise are so exceptional as to be almost unique. They have special significance as witnesses regarding the theories of coral-reef formation, and will be considered in detail in later sections.

The great lagoon enclosed by the Tagula barrier reef is divided by the satellite islands of the Calvados chain into a smaller northern and a larger southern compartment. The northern compartment measures about 25 miles east-west by 10 miles across, and occupies about one-sixth of the entire reef-enclosed space, which must approach 2000 square miles in total area. The southern compartment measures about 112 miles east-west by 20 miles across, and occupies about four-sixths of the enclosed space; the remaining sixth is taken by Tagula and the Calvados islands. The greater part of the lagoon floor, at a moderate distance from the outer reef and from the inner islands, is a very gently undulating surface, as a rule from 25 to 38 fathoms in depth; numerous soundings show the bottom to be covered with sand and coral. The lagoon floor rises gradually toward the outer reef and more rapidly toward the inner islands. The greatest depths, 49 fathoms in the central part of northern or smaller compartment (Fig. 10) and 46 fathoms in the southern or larger one, are in both cases much nearer to the dividing island chain than to the surrounding barrier reef. Where the reef is near the enclosed islands, the narrower lagoon is reduced in depth (Figs. 6, 12 and 13). Occasional reef shoals and

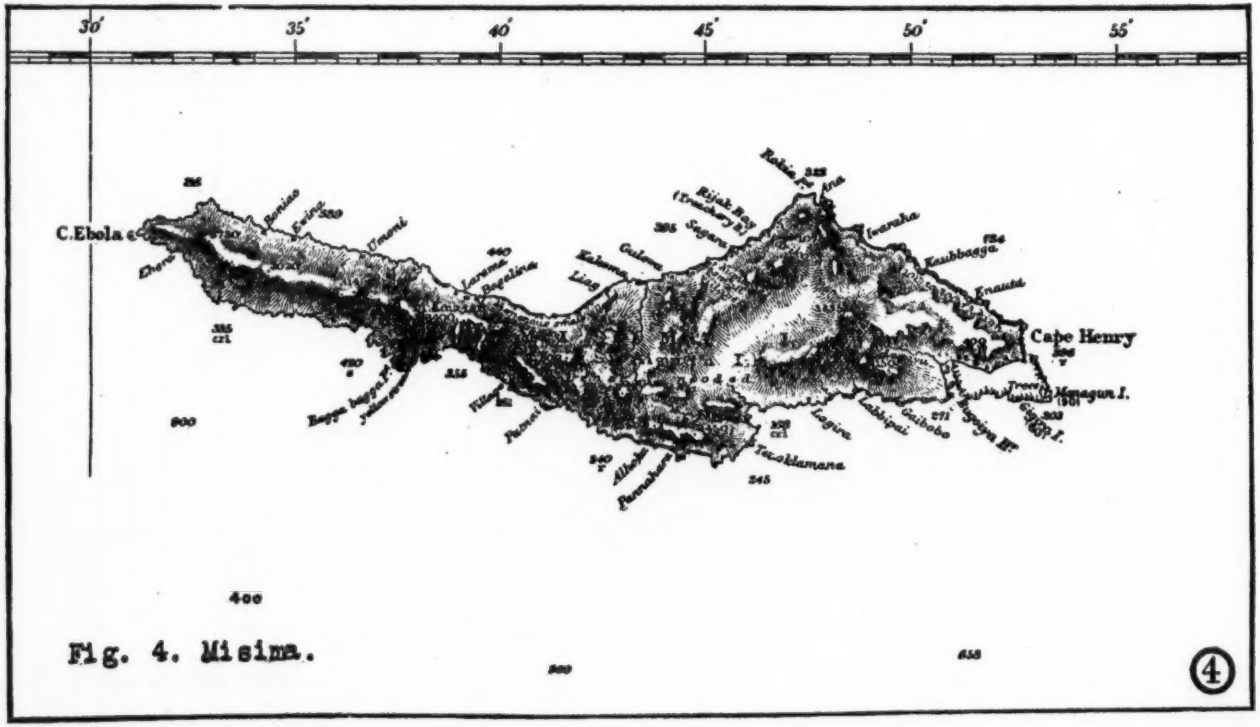

Fig. 4. Misima.

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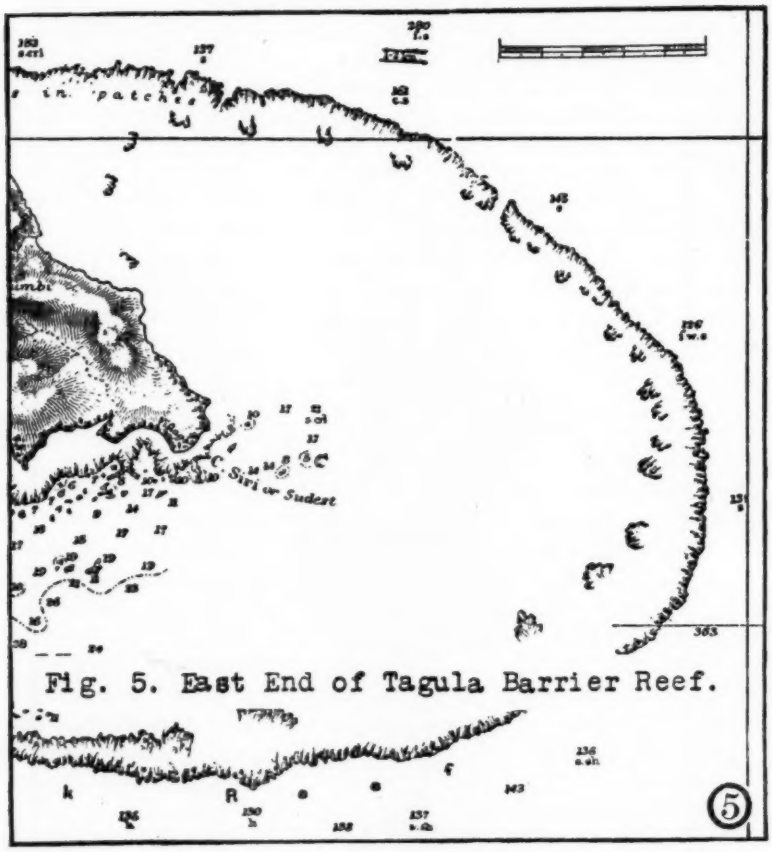

Fig. 5. East End of Tagula Barrier Reef.

patches and a few "lagoon atolls" of small size rise from the lagoon floor. The exterior slope of the barrier reef falls off rapidly into deep water. A few off-shore soundings outside of the barrier show depths of over 600 fathoms two miles from the reef on the northwest and north. Such are the chief facts concerning Tagula presented by the charts.

If the waters of the ocean were removed, Tagula and its satellites would appear as relatively low mountains emerging from the almost level surface of a large and steep-sided plateau, which would stand about 2000 feet above the surrounding bed of the ocean. The barrier reef would form a low rampart around the plateau margin; the rampart would be level, broad, regular, and almost continuous on the south-

Fig. 6. Middle of Tagula.

east, but narrower and irregularly discontinuous on the northwest; and the rampart loops in the northwest, all rising to the same level, would be surmounted by the small outpost islets, a few of which would be twice as high above the rampart as it is above the adjoining surface of the lagoon plateau.

Rocks of Tagula and Its Neighbors.—The few geological observations that have been thus far made in the Louisiade archipelago[1] show that the principal islands are composed for the most part of steeply inclined and greatly eroded schists and slates, trending about east-west, like the similar rocks in the northern ranges of New Guinea; but a few of the Tagula satellites are partly or wholly composed of basalt, and most of the outposts appear to consist of elevated and eroded reef limestone. Gold has been found in no great quantity on some of the islands.

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1 J. Macgillivray. Narrative of the Voyage of H. M. S. Rattlesnake. 2 v. London, 1852. Huxley was the surgeon on this surveying vessel. Mica slate is reported on the northwest coast of Tagula, I, 210, and not far away on Pig Island (Nimea), I, 188; Brierly island (Dadda hai), I, 232, has mica slate and talc and chlorite schists.

B. H. Thompson. New Guinea: Narrative of an Exploring Expedition to the Louisiade and D'Entrecasteaux Islands. Proc. Roy. Geogr. Soc., 1889, 525–542. Tagula, here called "Sudest," was visited at Coral Haven, near the west end of its north coast, and found to consist "of a slaty formation with veins of crystalline quartz running through it in all directions." Joannet, the largest of the Calvados chain, near Tagula, showed "slate with veins of quartz;" Misima, schistose slate and recently uplifted "coral," cut by mountain torrents. The three D'Entrecasteaux islands, Normanby, Ferguson and Goodenough, lying not far north of the eastern end of New Guinea are described as of similar composition with some volcanic rocks. Admiralty Chart 938 shows these islands to be somewhat embayed and not cliff; some of the points have very narrow fringing reefs; soundings around them are few.

A. G. Maitland. Geological Observations in British New Guinea. Queensland Geol. Survey, Publication No. 85, 1892. This report includes three large maps with partial geological coloring. The larger Louisiade islands, as far as colored and described, consist chiefly of schist. Basalt occurs in several islands at the western end of the Calvados chain (part of Moturina, and all of Ululina, Venariwa, Panarora) and in 4 near-by outposts (Gulewa, Utian, Pana-roba and Rara). Two other outposts farther southwest (Panasia and Pana-vara-vara) are colored as elevated coral limestone. The composition of most of the islands in the Calvados chain and of most of the smaller outposts is not indicated. Misima is made chiefly of schist with terraces of elevated reefs at various altitudes.

A. G. Maitland. Salient geological features of New Guinea. Journ. W. Austral. Nat. Hist. Soc., II, 1905, 32–56. This paper is chiefly an abstract of the preceding report. Kimuta, the largest of the Renard islands north of Tagula, is a "raised coral reef." The account of Misima island, p. 41, is followed by a paragraph beginning: "On the northern coast," as if referring to this northern island of the Louisiade group; but comparison with the earlier report shows that the northern coast of the eastern part of New Guinea is intended.

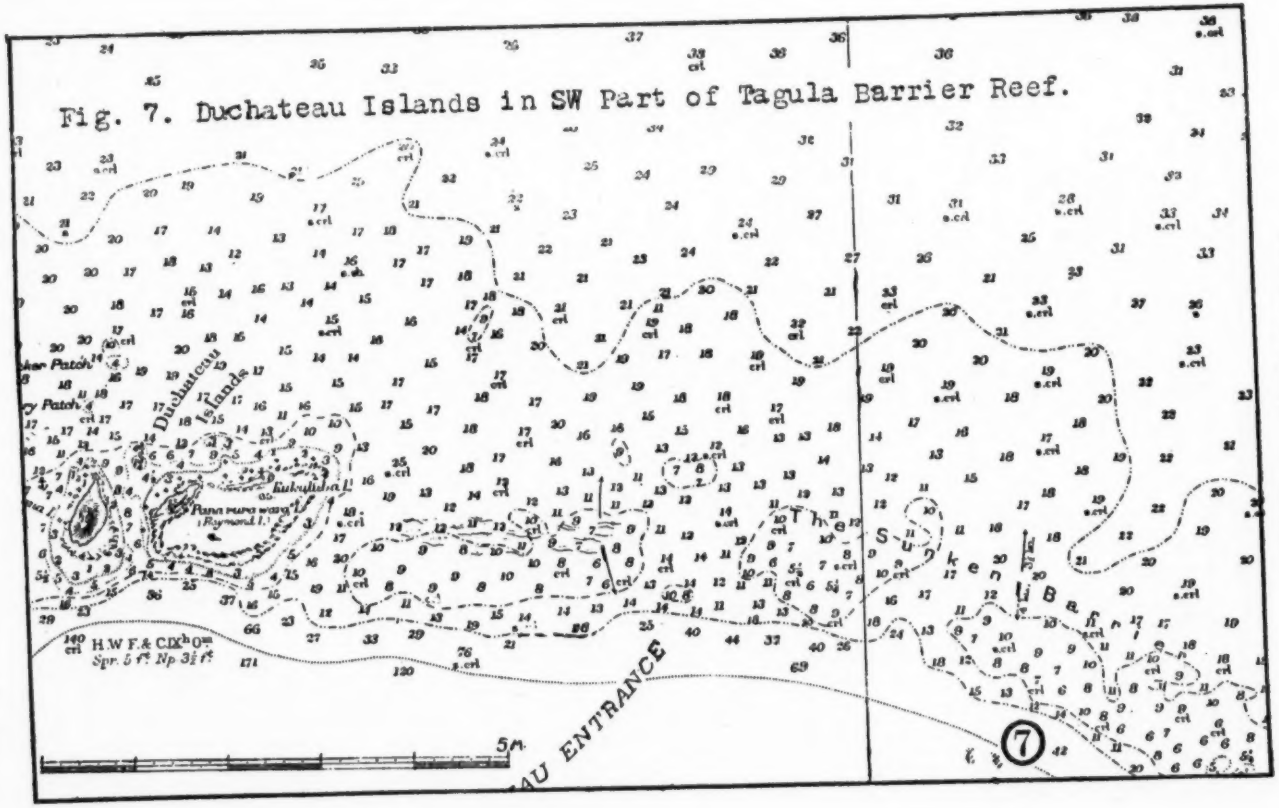

Fig. 7. Duchateau Islands in SW Part of Tagula Barrier Reef.

Inferences Based on Charted and Reported Facts.—Tagula and its satellites, as well as Rossel, Panniet and Misima, appear to be the higher parts of an eastward submarine extension of the mountain ranges of northern New Guinea. The structure, form and trend of the islands and their relation to each other strongly suggest that the portions of the range which they represent had reached a mature or later stage of erosion while the whole region stood higher than now, and that the separation of the archipelago from New Guinea, and of the islands in the archipelago from each other, was brought about by a geologically modern submergence. The fauna of the islands also suggests a recent separation from New Guinea. The amount of pre-submergence erosion appears to be immensely greater than could have been accomplished during the lowered stands of the ocean in the Glacial epochs of the Glacial period; and the depth of submergence indicated by inter-island soundings is many-fold greater than the most liberal estimate of the change of ocean level during the Glacial period. Hence the submergence is presumably due chiefly to a strong subsidence of the region, increasing eastward, in comparison with which the fluctuations of ocean level during the Glacial period were small and short-lived.

It is, however, also conceivable that the larger islands and the Calvados chain represent faulted crustal blocks, instead of the higher parts of a continuous range; but even if so, the several blocks must for a time have stood much higher than now in order to be eroded to their present form before they were submerged to their present attitude; for as far as can be inferred from the dimensions of the island valleys and of the valley embayments, the erosion is, as already noted, too great in amount, and appears to be continued too far below present sea level, to have been accomplished during the lowered stands of the ocean in the Glacial period. Hence it may be concluded that, even if the islands represent fault blocks, their present form, including their submarine slopes to a considerable depth, could not have been sculptured during the lowered stands of the Glacial ocean, and their present depth of submergence could not have been caused by the rise of the ocean in Postglacial time. Whether the islands are the unfaulted crests of a long mountain chain or the crests of a series of blocks in a faulted range, they point to a pronounced subsidence of the deformed and eroded mountain belt in geologically modern time.

The instability of the region is further indicated by certain differential movements, modern in date and of no small amount, of which the contrasts between Misima and the other islands of the group, and between the northern and southern coasts of eastern New Guinea give striking evidence. Tagula and its larger satellites, as well as Rossel, are not described as having elevated reefs on their flanks, but are sur-

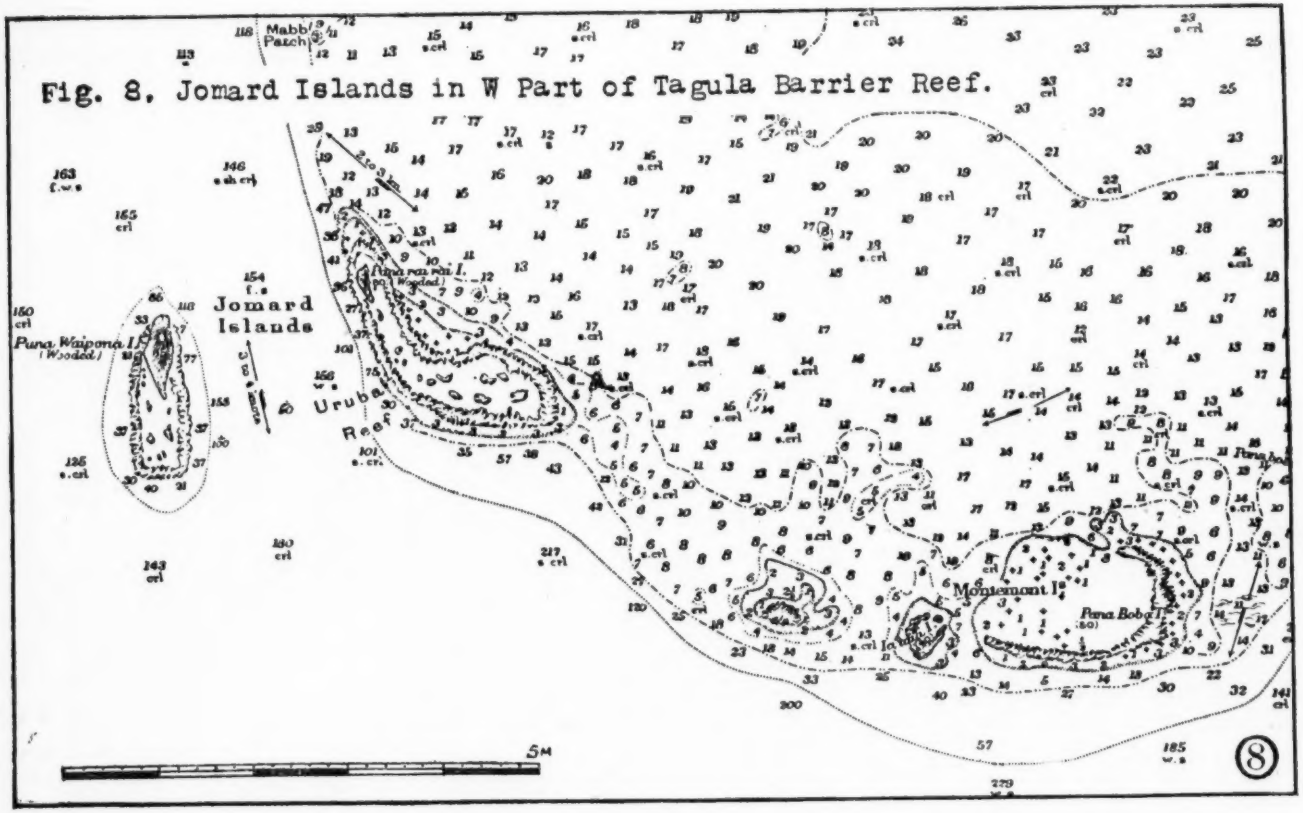

Fig. 8. Jomard Islands in W Part of Tagula Barrier Reef.

rounded by great barrier reefs and lagoon floors at and a little below present sea level; yet that some of the Tagula satellites bear remnants of elevated reefs will be suggested below. A little farther north, Panniet, 1500 feet in height, and its small companion, Panapompom, are likewise associated with a sea-level barrier reef as in Figure 3; but here an elevated reef, 10 feet above sea level, is said to occur on the north side of the lagoon. Maitland is quoted as reporting that "reefs raised only a few feet above the sea level, such as those of Pannietta, present along the shore white perpendicular cliffs of varying height, above which is an almost level tableland, very broken and rugged, and with a very uneven surface."[2] Panniet is peculiar in having no reefs on its northern side, where it is charted (Fig. 3) as having cliffs which descend into deep water; these cliffs appear to be much higher than the "few feet" of the reef cliffs reported in the lagoon by Maitland.

Still farther north, Misima (Figs. 4, 14 and 15) presents very different features. This island, measuring 22 by 10 miles and rising 3500 feet, slopes rapidly into deep water and, except at its southeastern point, has no sea-level reefs; but it is according to Maitland terraced by elevated reefs to considerable altitudes above sea level, and some of the reefs were found to rest unconformably on the eroded schists of the island slope. This observer reports that the "elevated reef masses [of Misima] when viewed from a distance, presented the appearance of vertical walls and almost horizontal terraces, stretching often for considerable distances. The faces of these cliffs are sometimes covered with vegetation to such an extent as to present the appearance of huge walls of foliage. The thickness of these reef masses I had no opportunity of ascertaining; it is, however, improbable from their mode of occurrence that their vertical thickness can be very great."

The southern coast of eastern New Guinea is, like Tagula, fronted by a long barrier reef. The northern coast (Figs. 21, 22) descends rapidly into moderately deep water and is bordered only by narrow and discontinuous fringing reefs at present sea level; and at certain points it has, again according to Maitland, coral limestones remarkably well preserved and resting unconformably on the older rocks at various levels up to altitudes of 2000 feet.

On Misima the unconformity of the elevated reef limestones on their foundations proves a submergence before the recent emergence;

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[2] Jack and Etheridge. Geology and Paleontology of Queensland and New Guinea, London, 1892; see p. 685.

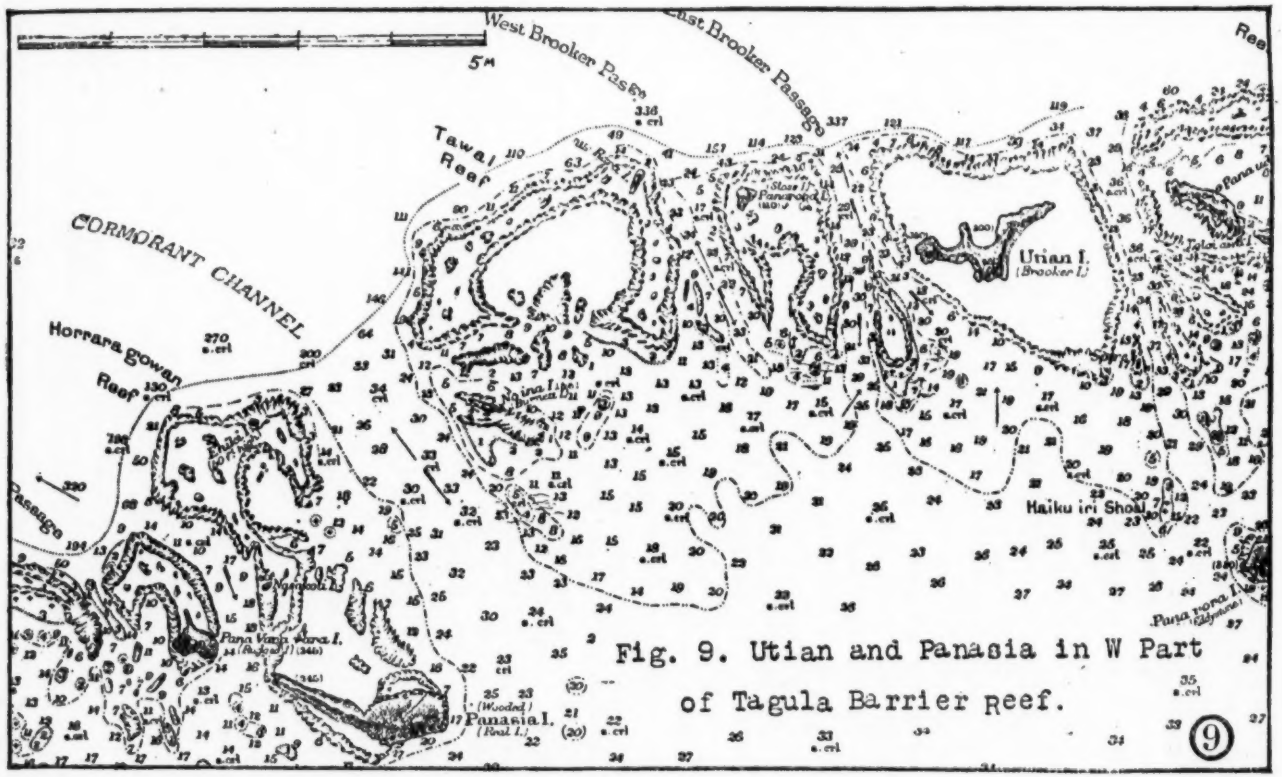

Fig. 9. Utian and Panasia in W Part of Tagula Barrier Reef.

and the submergence must be estimated as greater than the emergence, because the eroded slopes of the land descend below present sea level.* This is well shown by the embayed shore line of Misima, especially its western part, as in Figure 14. It is probable that, but for the reef terraces of this island, some of which lie near present sea level, its shore line would be decidedly more irregular than it now is. Whether the elevated reefs were made during pauses in an intermittent submergence before a rapid emergence, or whether a rapid submergence was followed by an intermittent emergence, with reef building during its pauses, or whether some of the reefs were formed during pauses in submergence and some during pauses in emergence cannot now be determined; but there can be no question that the submergence of Misima, presumably caused by subsidence, was at times more rapid than the rate of reef upgrowth.

Similar inferences are supported by the features of eastern New Guinea along its northern coast. Its easternmost end is itself embayed, and is continued by several elaborately embayed islands, which are shown on Hydrographic Office Chart 2950 and of which as well as of the northern coast for some distance westward, a general description is given by Moresby, a recent and yet the first explorer of that region.[a] There are parts of the northern coast here shown in Figures 21 and 22, where, as around Misima, sea-level reefs are imperfectly developed or wanting. The second of these figures, including the great volcanic mountain of Trafalgar with its beautifully embayed shore line, is particularly striking. This dissected volcanic mountain resembles that of Banks peninsula on the eastern coast of South Island, New Zealand, except that the latter being outside of the coral seas, was strongly clift by the sea while it was dissected by radial consequent streams; but Trafalgar, which Moresby says descends " to the sea in open grassy and wooded slopes," appears to have been protected from abrasion, probably by coral reefs as it is inside the coral seas, while it was suffering dissection. The cliffs of Banks peninsula are still in part visible, in spite of the embayment of its valleys. If cliffs had been cut around the base of Trafalgar while its valleys were eroded, they might be seen today as plunging cliffs now that the valleys have been embayed. The scanty information in hand about this region does not suffice to determine the relation of the general erosion of the mountain slope on which the ele-

* The importance of unconformable reefs is pointed out in one of my essays: The Geological aspects of the coral-reef problem. Science Progress, XIII, 1919, 420–444.

[a] J. Moresby. Recent Discoveries in the southeastern part of New Guinea. Proc. Roy. Geogr. Soc., XVIII, 1873, 22-31. See also, "Discoveries and Surveys in New Guinea," by the same author (*London*, 1876)

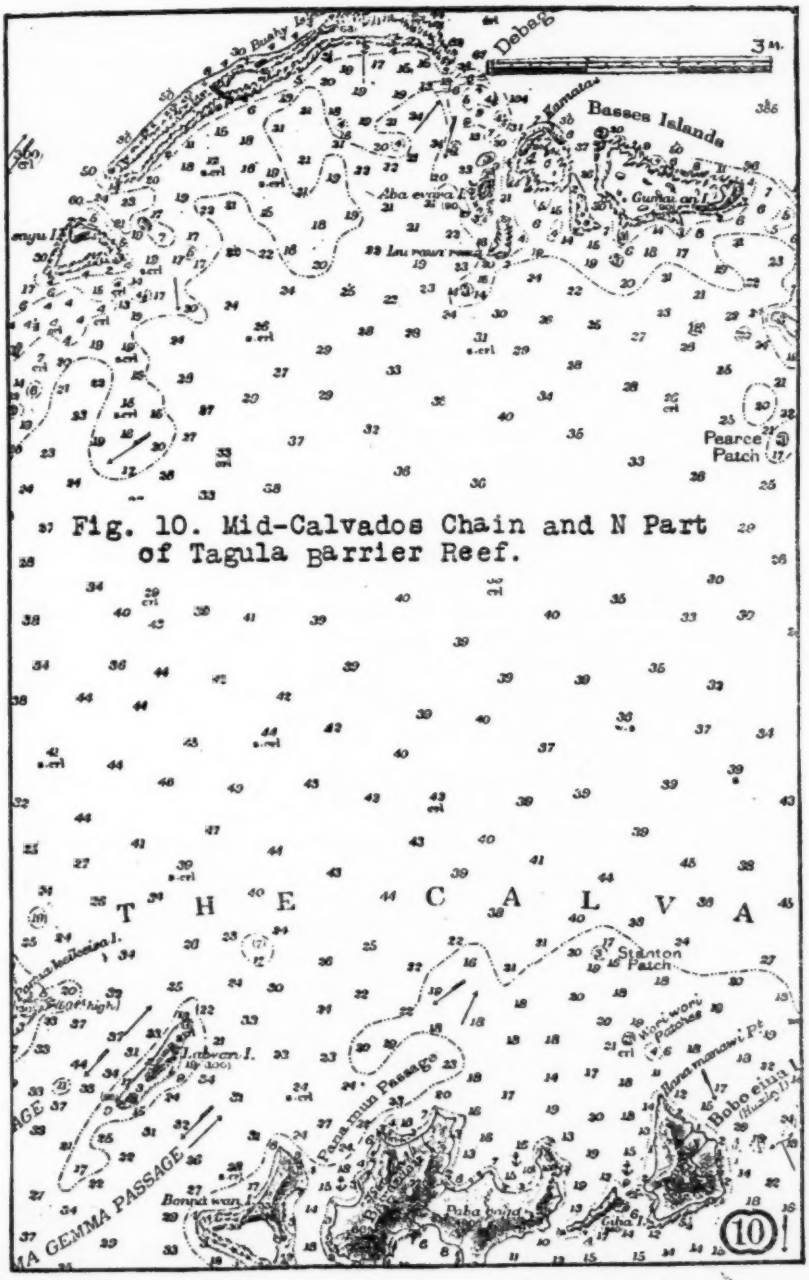

Fig. 10. Mid-Calvados Chain and N Part of Tagula Barrier Reef.

vated unconformable coral reefs rest, as reported by Maitland, to the erosion of Mt. Trafalgar; nor the relation of the changes of level shown by the elevated reefs to the changes of level shown by the present embayed shore line; but in any case the coast must be regarded as markedly unstable, and as having experienced strong differential movements in very late geological time.

Smaller differential movements, possibly of earlier date, as explained below, are indicated by the elevated coral limestones reported on certain outpost islets and inferred on others around the northwestern part of the Tagula barrier. Very recent movements are suggested by the "sunken barriers" or submerged reefs, examples of which are found not only in the southwestern part of the Tagula barrier (Fig. 7), as already stated, but again and on a much larger scale along the southern side of New Guinea. There, in a total length of 380 miles, the barrier reef, as represented on British Admiralty Charts 2122, 2123, is submerged for two stretches of about 60 and 140 miles; the imperfectly enclosed lagoon varies from five to 20 miles in width; back of the longer stretch of the submerged barrier the lagoon, which is ordinarily 20 or 30 fathoms deep, has the unusual depths of from 45 to 59 fathoms. In view of the successful growth of sea-level barrier reefs elsewhere in this region, these "sunken barriers" appear to be better explained by local and gentle down-warping of pre-existent sea-level reefs at a rapid rate and a very recent date, than by a local failure of reef upgrowth from a stable foundation. They may in time be built up to sea level again.

Relation of Crustal Instability to Reef Formation.—In consideration of these various facts and inferences, it may be concluded, with much probability of correctness, that long after the strong deformation by which the rocks of the region were given their steep inclination with eastward trends, and not until the attainment of an advanced stage in the great erosion which began with but long outlasted the strong deformation, the Louisiade extension of eastern New Guinea suffered a pronounced subsidence or down-warping, increasing eastward; and that at a still later date the northern border (Misima) and the western part (eastern New Guinea) of the region suffered an upheaval or up-warping of less amount. This conclusion, which has been reached by inferences that are independent of all coral-reef theories, seems to make it necessary to explain the great submarine body of the sea-level barrier reefs in the Louisiade by upgrowth during the progress of the subsidence. The great submarine mass of the barrier reef of Tagula, with which we are here particularly concerned, should therefore be regarded as having grown up during the long continued

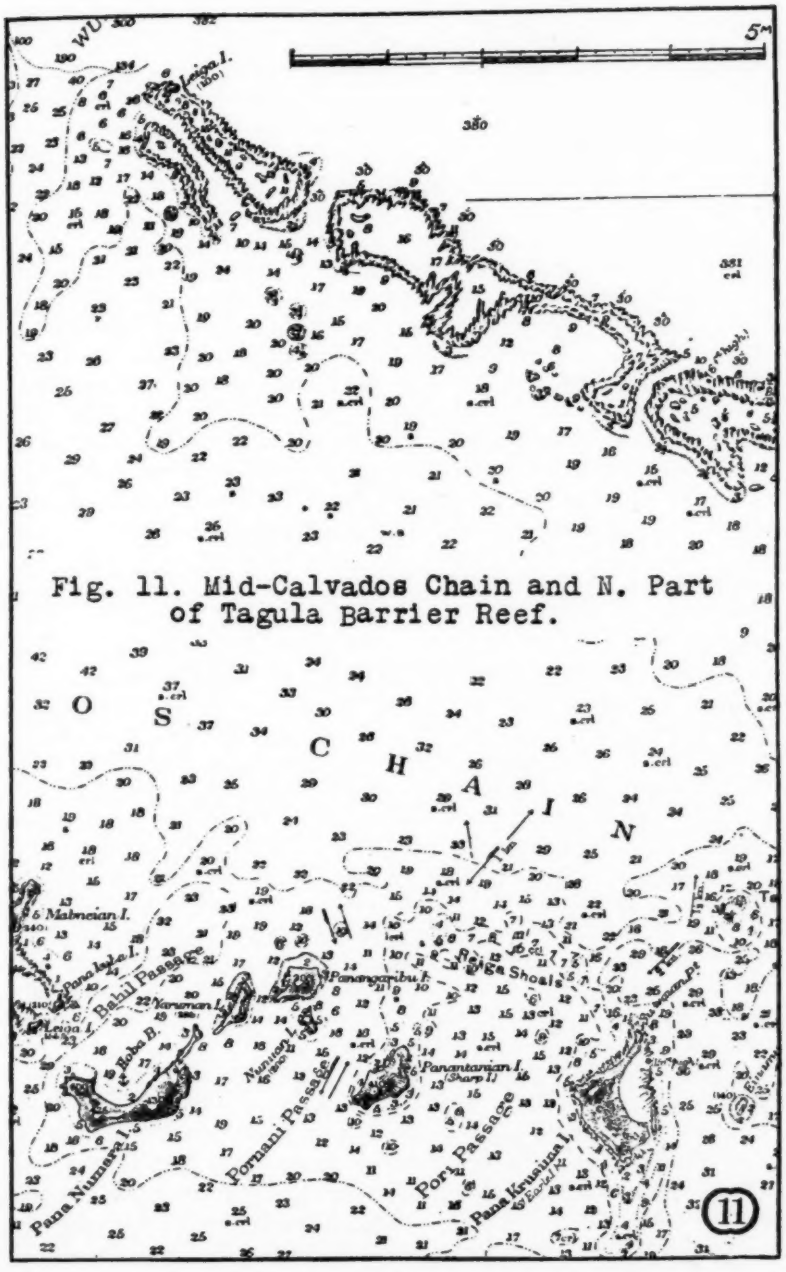

Fig. 11. Mid-Calvados Chain and N. Part of Tagula Barrier Reef.

and probably intermittent subsidence of its original foundation, which now lies at an unknown depth; and during such subsidence the enclosed lagoon floor should be conceived as having been progressively aggraded with sediments of unknown thickness, essentially according to Darwin's theory, whatever subordinate changes recently took place during temporary movements of upheaval and during the fluctuations of sea level in the Glacial period. Those changes will further be inquired into in later paragraphs.

Suggested Origin of Outpost Islets and Reef Loops.—Both of the singular features by which the northwestern half of the Tagula barrier reef is so strikingly characterized are encountered rarely, if at all, elsewhere in the coral seas. Their intimate association here suggests that they are causally connected. The reef loops cannot have produced the outposts, but the outposts may have, under certain relatively simple conditions, determined the formation of the reef loops, and the manner of that determination will be here inquired into.

Two of the larger outposts, Gulewa and Utian, at the western end of the Calvados chain, are described by Maitland as composed of volcanic rocks, like other western Calvados islands. In two small outposts, Pana-roba and Rara, west of Utian (Fig. 9), Maitland says "basalt occurs;" and Panasia, rising 530 feet, the highest of all the outposts, and its neighbor, Pana-vara-vara, 345 feet high, are colored on his geological map as consisting of "elevated coral limestone." The other outposts, a score in number, are of unknown composition, mostly of very small size, and from 40 to 120 feet in height. It is not likely that the majority of them are made of volcanic rocks like Utian, or of schists like Tagula and its larger satellites, because the intimate association of volcanic or of schist islets with the loops of the great barrier reef would be difficult to explain without the adoption of utterly improbable assumptions. On the other hand, if the outposts are regarded as for the most part residuals of a former barrier reef, here uplifted and much eroded and then partly submerged, their explanation offers no difficulty, in whatever way the preexisting barrier reef was formed. This view as to the origin of the small outposts and of the reef loops within which they rise is therefore provisionally adopted, and will now be stated more fully.

Let it be imagined that the northwestern part of the Tagula barrier-reef region was uplifted not long ago geologically 300 or 400 feet, while the southeastern part remained about stationary. The uplifted part will have been protected from wave attack by the downward migration of living fringing reefs on its emerging slopes; while its emerged part will have been gradually reduced, chiefly by solvent erosion, to

Fig. 12. East Part, Calvados Chain and Adjoining Barrier Reef.

residual masses of irregular form. When the erosion is well advanced, let a subsidence of 200 or 300 feet take place at such a rate that the fringing reefs will grow up as small barrier-reef loops around each of the residual summits of the eroded barrier. If the ocean suffered a Glacial lowering of level while the reef was elevated and a Glacial rise of level when the elevated reef subsided, the changes due first to erosion and then to reef-loop upgrowth would be emphasized. Each low summit that is completely submerged will be replaced by a little atoll loop; each higher summit, still visible today as an islet, will be surrounded by a little barrier-reef loop of similar outline. Most of the loops will be elongated in sympathy with the curve of the former barrier reef. The surviving islets will resemble, except for being smaller, the much eroded limestone islands now enclosed by the barrier reefs of southeastern Fiji, as figured by Agassiz.[4] Thus the peculiar features of the Tagula barrier reef may be explained.

Reasonable as this explanation may seem, it should not be adopted definitely until the composition of the outpost islets is determined by direct observation. But in the meantime some additional consequences of the explanation may be noted. First, if the northwestern half of the former barrier were moderately uplifted, the islands of the Calvados chain should have suffered a similar uplift; and for a while thereafter they should have been benched with emerged fringing reefs; but after a time long enough for the advanced erosion of the main barrier reef, the fringing reef benches should be largely or wholly destroyed, thus revealing the maturely eroded underlying slopes of the schist islands more or less completely. Then after subsidence, an island on which steep-sloping remnants of the emerged reef were still clinging might have steep spur ends. This is warranted by the forms of Vanua Mbalavu in eastern Fiji, an island that is believed to have suffered essentially the same series of changes of level that are here assumed for the great Tagula barrier. It has the sloping spurs of a maturely eroded volcanic island on one side, and on the other the precipitous cliffs of a greatly dissected body of limestone which must have formerly wrapped around the entire island. Some of the Calvados islands have precipitous spur ends, as will be shown below. It is therefore possible that they may have been formed as here proposed. But as above noted, no decision on this point should be announced in advance of detailed observations as to the composition of the islands.

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[4] A. Agassiz. The Fiji islands and coral reefs. Bull. Mus, Comp. Zool., XXXIII, 1899, 1–167; see plates 83, 90, 94.

W. M. Davis. The origin of certain Fiji atolls. Proc. Nat. Acad. Sci., II, 1916, 471–475.

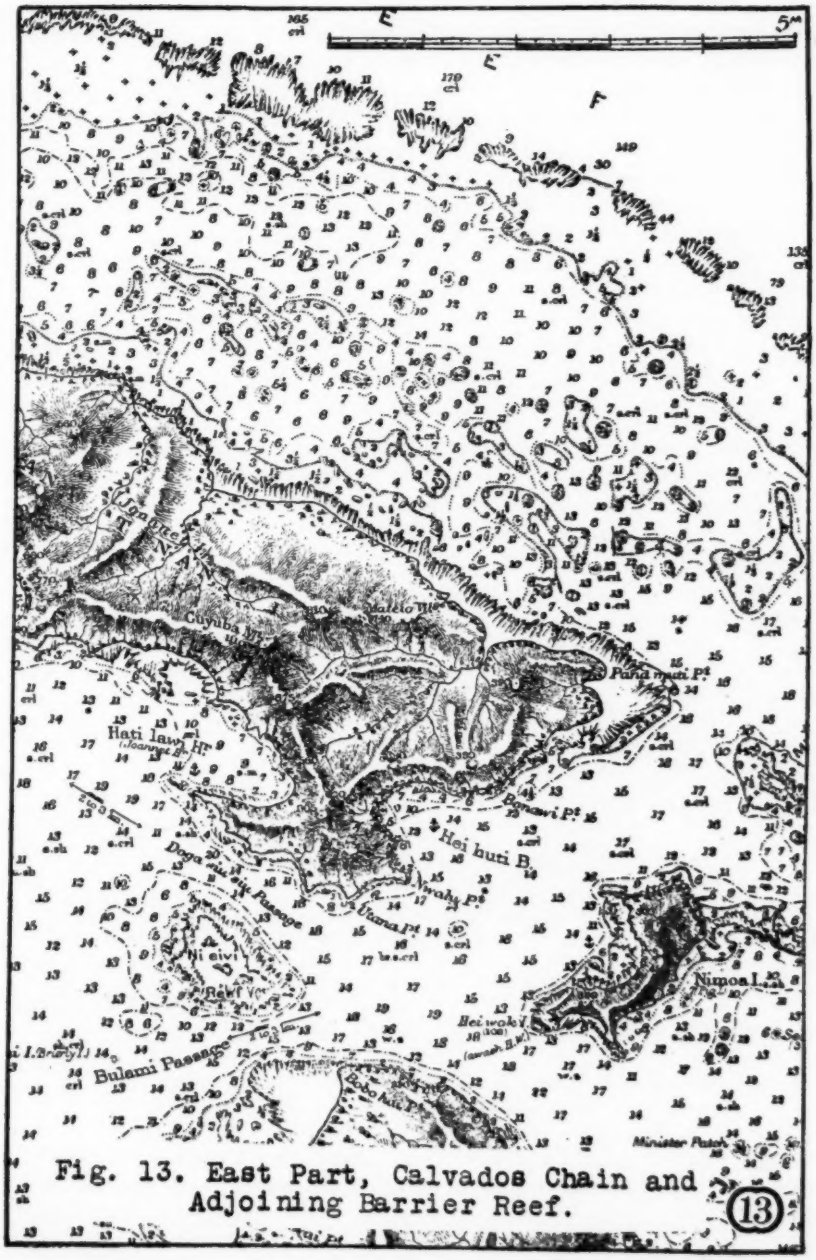

Fig. 13. East Part, Calvados Chain and Adjoining Barrier Reef.

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Second, the assumed elevation of 300 or 400 feet may have laid bare the northwestern part of the Tagula lagoon floor as a gently sloping limestone plain, which would thereupon be subjected to erosion. If, as above suggested, the Glacial lowering of ocean level took place while the reef and the adjoining part of the lagoon floor were elevated, the lagoon-floor plain might have been eroded with respect to a baselevel some 30 fathoms below normal ocean level. When the barrier reef had been eroded so far that its summits were reduced to the form of the present outpost islets, the lagoon-floor might have been worn down to a plain nearly as low as the lowered ocean. If a subsidence of 20 or 25 fathoms then took place and was associated with, or followed by, the rise of the ocean to normal level, the worn-down lagoon-floor plain would be submerged to a depth of 50 or 60 fathoms; but aggradation of the submerged plain by inwashed and local detritus would give the present lagoon floor its actual depth of from 30 to 45 fathoms.

Third, emergence and submergence caused by changes of ocean level will not alone suffice to account for the features of the Tagula barrier reef; because in that case many other barrier reefs should have similar outpost islets enclosed in little reef loops, and such is not the case. A moderate elevation and a smaller subsidence of the northwestern part of the Tagula region, associated with Glacial changes of ocean level, give a better explanation of the facts.

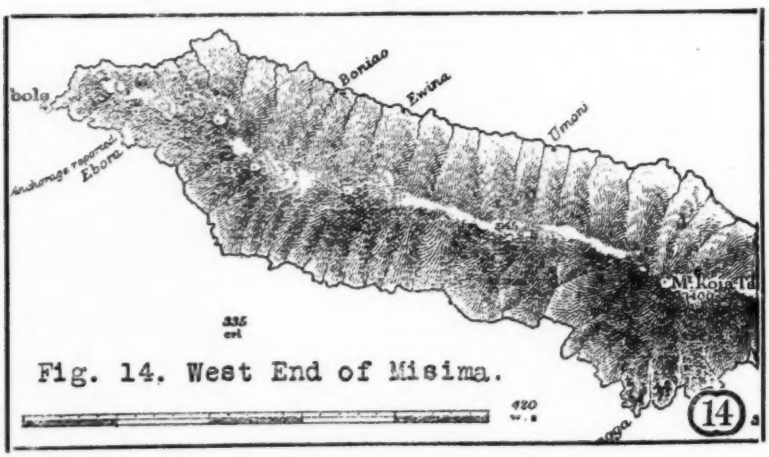
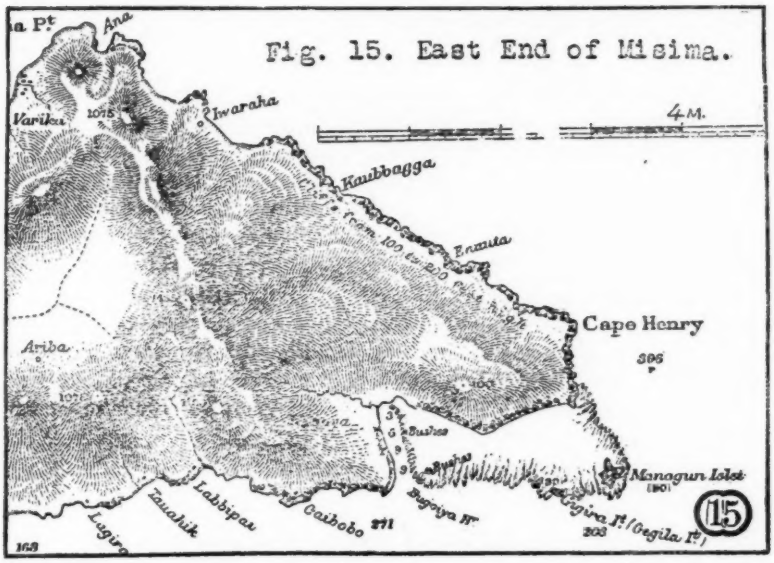


Fig. 14. West End of Misima.

Fourth, while the changes were taking place in the northwestern part of the Tagula barrier, the reefs in the more nearly stationary southeastern part should increase in breadth. This inference is well sup-



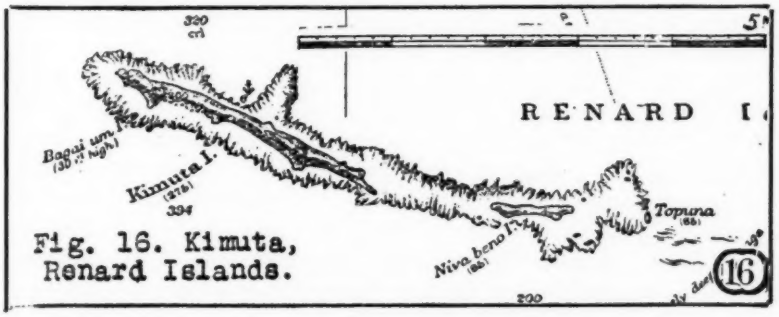


Fig. 16. Kimuta, Renard Islands.

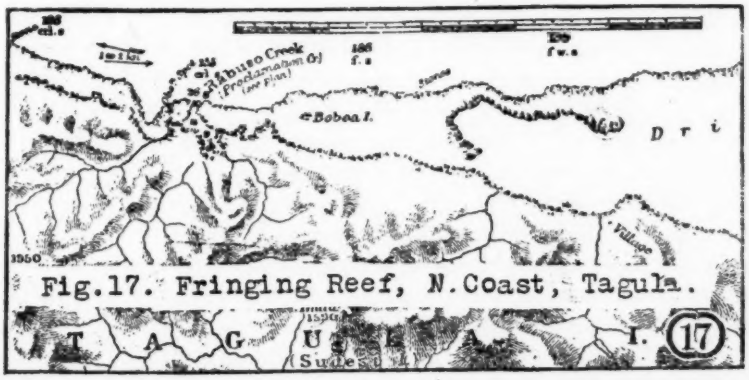


Fig. 17. Fringing Reef, N. Coast, Tagula.

ported by the facts, as here represented in figures of the islands and reefs.

Fifth, if the northwestern part of the Tagula barrier reef has been thus uplifted, eroded, and submerged, similar changes might be expected to have taken place on some of the neighboring islands, and these changes should be there also recorded by the occurrence of outpost islets in their reefs. An examination of the charts reveals truly enough several minute outpost islets in the Rossel reef; Figure 18 shows Tree islet, 40 feet high; Figure 19 shows Heron islet, 30 feet high; and Figure 20, Adele islet, 130 feet high: the situation of the last outpost at the eastern extremity of the Rossel barrier is certainly very exceptional. The eastern end of Misima (Fig. 15) is peculiar in being bordered by a mile-wide fringing reef; and two outpost islands rise from it; Managan islet, 90 feet, and Gegila islet, 80 feet; the probability that these outposts islets are composed of elevated reef rock is increased by the reported occurrence of elevated reefs on Misima.

The southeastern part of the Panniet barrier reef, which approaches the northern turn of the Tagula barrier, has a small outpost islet (Fig. 3), 80 feet high; and a detached triangular reef of small size between the two barriers not shown in the figures, has an islet marked "trees 90 feet high." Kimuta, the largest of the Renard islands which lie southeast of Misima, is shown (Fig. 16) to be a slender ridge, three miles long, one-quarter mile wide, and 275 feet high; it is described by Maitland as a "raised coral reef." Near by is the smaller Nivabeno island, 85 feet high; also two minute outposts, 30 and 65 feet high. The resemblance of Kimuta to Sabari, the largest of the Tagula outposts (Fig. 12) is very striking. Sabari is a mile longer than Kimuta, about twice as wide and half as high; and, like Kimuta, it is associated with minute neighboring islets. Finally, the western of the two Jomard islands (Fig. 8) with its reef loop two miles long and its outpost islet 85 feet high, although separated from the Tagula barrier by a water passage two miles wide and over 150 fathoms deep, closely resembles the eastern of the two islands, which makes part of the Tagula barrier, with its reef loop three miles long and its somewhat smaller outpost 80 feet high. None of these outpost islets, except the western Jomard, are enclosed in reef loops like those of the Tagula barrier; they rise from broad reef flats. Otherwise they are very similar to the Tagula outposts. Hence as above stated the proposed explanation of the Tagula outposts by an episode of elevation, erosion and subsidence is provisionally adopted. Similar episodes may have characterized earlier stages of the great subsidence.

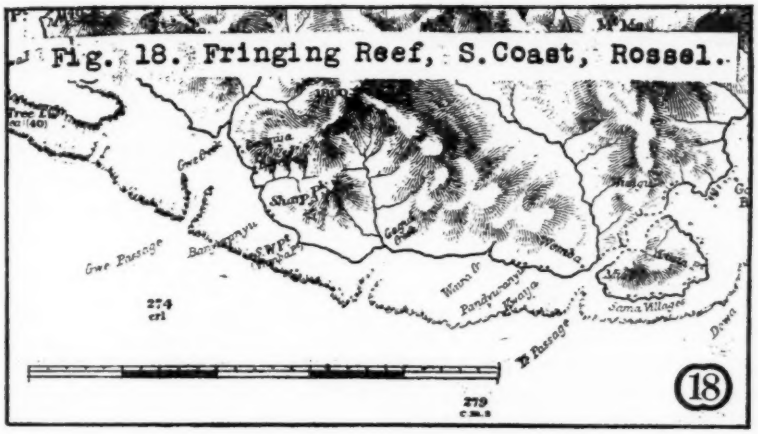


Fig. 18. Fringing Reef, S. Coast, Rossel.

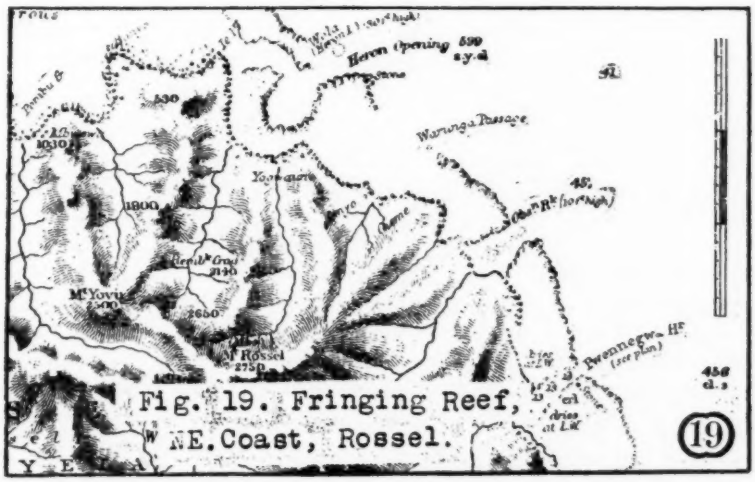


Fig. 19. Fringing Reef, NE. Coast, Rossel.

Abrasional Theories of Coral Reefs.—The charts of the Louisiade islands are particularly instructive because of the evidence, to be detailed below, which they afford against the validity of certain coral-reef theories in which abrasion plays a leading part. It has been urged by the proponents of these theories that the prevailing flatness of lagoon floors cannot be explained by the distribution of aggrading sediments in great thickness on subsiding foundations of uneven form, so well as by their distribution in small thickness on nearly level platforms abraded at a standard depth around stationary islands. One such the-

ory was announced some 30 years ago by Wharton, but it gave no reason for the absence of defending reefs while abrasion was in progress; the theory nevertheless tacitly postulated their absence and implied furthermore that the abrasion to at least as great a depth as that of lagoon floors was accomplished while the ocean and the islands held their present relative levels. In view of the depths of 30 fathoms commonly found in reef-enclosed lagoons, and of over 40 fathoms found in both compartments of the Tagula lagoon, this theory seems inadequate.

Another abrasional theory recently advanced by Daly[5] is much better argued, in that it assumes abrasion to have taken place while reef-forming organisms were weakened or killed by the chilling of the ocean during the Glacial epochs of the Glacial period, and in that it accounts for the roughly accordant depths and smooth floors of barrier-reef and atoll lagoons by assuming that sub-lagoon platforms were abraded while the chilled Glacial ocean was lowered 30 fathoms or more beneath its normal level. It is especially because of the evidence that the Tagula reef system affords regarding the postulates and processes of this so-called Glacial-control theory of coral reefs that it is here examined.

The examination has already led to the belief that the Louisiade region is characterized by instability which, as the Glacial-control theory recognizes, is prevalent in the southwestern Pacific, and that Tagula in particular appears to have suffered strong subsidence. It may now be added that, in spite of this subsidence, the large lagoon has a depth that accords very well with the depth of large reef-encircled lagoons in the central Pacific region which is assumed in the Glacial-control theory to be of long-continued stability. Hence it may be concluded that, contrary to the argument of that theory, the stability of reef foundations does not seem to be essential for the production of lagoons with accordant depths. A further examination, detailed below, leads to the belief that no significant amount of abrasion was accomplished around Tagula by the chilled waters of the lowered Glacial ocean; therefore the smooth floor of the great lagoon should not be

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[5] R. A. Daly. Pleistocene glaciation and the coral reef problem. Amer. Journ. Sci., XXX, 1910, 297-308.

— — The Glacial-control theory of coral reefs. Proc. Amer. Acad. Arts and Sci., LI, 1915, 157–251.

— — Problems of Pacific islands. Amer. Journ. Sci., XLI, 1916, 153–186.

— — A new test of the subsidence theory of coral reefs. Proc. Nat. Acad. Sci., II, 1916, 664–670.

— — Origin of living coral reefs. Scientia, XXII, 1917.

— — The coral-reef zone during and after the Glacial period. Amer. Journ. Sci., XLVIII, 1919, 136–159.

regarded as the result of relatively moderate Postglacial aggradation on a stationary abraded platform, but as chiefly the result of long-continued and heavy aggradation on an uneven and slowly subsiding foundation of whatever form, as is assumed in Darwin's theory. If this great lagoon has gained a smooth floor at a normal depth in spite of long-continued subsidence, complicated by recent elevation and without the aid of abrasion, it may be further concluded that the abrasion of flat platforms on supposedly stationary islands in the central Pacific, as assumed in the Glacial-control theory, is not essential for the production of smooth lagoon floors of accordant depths. I have elsewhere shown that a number of elevated and eroded limestone islands in Fiji, believed to have originated as atolls, show no abraded volcanic platforms.[6]

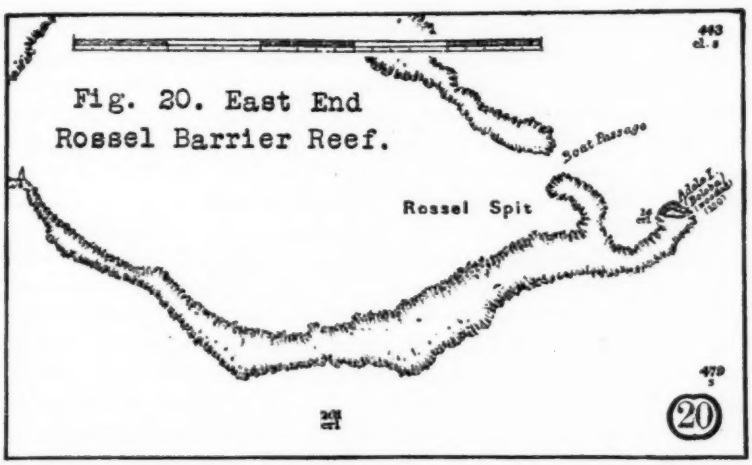


Fig. 20. East End Rossel Barrier Reef.

It may be that, in view of the situation of the Tagula reef, the advocates of the Glacial-control theory would regard its corals as having survived the small lowering of ocean temperature there occurring in the Glacial Period, and would not insist that its lagoon floor is underlaid by a platform of abrasion; but if such opinions were accepted, the resemblance of the Tagula reef to other barrier reefs and of its lagoon floor to other lagoon floors where abrasion is assumed to have acted, would be embarrassing: for the resemblance would suggest that, if inhibition of coral growth and abrasion of pre-existent reefs did not take place around Tagula, they surely need not be appealed to in the preparation of other reefs and lagoons. It will therefore be supposed

[6] The structure of high-standing atolls. Proc. Nat. Acad. Sci., III, 1917, 473-479.

here that the advocates of the Glacial-control theory would regard the Tagula reef as having been formed in the same manner as that adopted by them for the great majority of reefs in the coral seas.

Accordant Depths of Reef-Encircled Lagoons.—The tables of lagoon depths published by Daly—in which the Tagula lagoon was not included—show a certain measure of accordance. The larger lagoons have average maximum depths of from 30 to 45 fathoms; the smaller ones, from 15 to 25 fathoms. It is inferred thereupon that no such accordance should be found "if subsidence has been the essential control in forming coral reefs," and this inference is taken to support the thesis that "most of the reef platforms . . . have such forms, dimensions, and relations to the sea level that they appear to have originated during a long period of very nearly perfect stability for the general ocean floor."[7] Several other considerations may be here adduced. First, large lagoons should as a rule be deeper than small ones, by whatever process their encircling reefs have been formed, because the inwashed detritus from each linear foot of exterior reef face has to aid in the aggradation of a larger sector-area in a large lagoon floor than in a small one. Indeed, as large lagoons are deeper than small ones, it may be fairly stated as a corollary of this principle that a significant share of the detrital material by which lagoons are aggraded must have been supplied by overwash from the exterior of the reef, just as various observers have inferred to be the case in view of the composition of the lagoon sediments and of the inward slope found in many lagoon floors behind their reefs. As far as the detritus consists of organic material formed in the lagoon, its total volume may be regarded as increasing with the lagoon area and as therefore not tending to make small lagoons shallower than large ones. Second, the departures of the depths of individual lagoons from the average depth of other lagoons similar in size is relatively large; and this appears to be better explained by the theory of upgrowing reefs on irregularly subsiding foundations than by the theory of upgrowing reefs on the margins of platforms abraded to a nearly constant depth around stationary islands.

Third, and more important still, Daly's tables do not separate the lagoons in the central Pacific region of assumed "nearly perfect stability" from those in the southwestern region of admitted instability. When this separation is made, it appears that the average values gained from the tables are little changed. It would therefore seem fair to infer that, if reef-encircled lagoons in a region of demonstrated instability

[7] R. A. Daly. The Glacial-control theory of coral reefs. Proc. Amer. Acad. Arts and Sci., LI, 1915, 157–251; see pp. 194, 162.

usually accord in depth with the lagoons of similar size in a region of assumed stability, the assumption of stability for the second region is rendered improbable, to say the least. The Louisiade lagoons serve to confirm this inference. They are in a region of pronounced instability, and yet have smooth floors, and their depths are accordant with those of similar-sized lagoons elsewhere. The island of Tagula appears to have suffered strong and long-continued subsidence, recently complicated by a small upheaval; yet its great lagoon has maximum depths similar to, but somewhat less than, those of the lagoon of Truk, an almost-atoll in the Caroline group, about 35 miles in diameter, one of the largest reefs of its kind in the central Pacific. Although this lagoon had few soundings of more than 30 or 35 fathoms according to the earlier charts, it has depths as great as 56 fathoms according to later German surveys, and such depths are not much greater than the depth of 46 and 49 fathoms in the Tagula lagoon.

On the other hand, the smaller lagoons in the Louisiade region have smaller depths; witness the Rossel lagoon (Fig. 2), seven miles wide and 39 fathoms deep; the Panniet lagoon (Fig. 3), of similar width and 21 fathoms deep; also the narrower parts of the Tagula lagoon, from five to seven miles wide south of the island (Fig. 6), and 30 or 40 fathoms deep; also, north of the Calvados chain (Figs. 12 and 13), two to four miles wide and 16 fathoms deep. Certain atolls shown to the west of the Tagula barrier (Fig. 1) are of interest here: Bramble haven, 10 miles in diameter, is 20 fathoms deep; Long atoll, 5 by 18 miles, next to the west, has no soundings on H. O. Chart 2942; to the north, Conflict atoll, 5 by 12 miles, is 17 fathoms deep. In other words, the rule established by Daly's tables for the open Pacific of unknown crustal behavior holds good also for the Louisiade region of unquestionable instability. The large lagoons of this unstable region are 40 or 50 fathoms deep; the small lagoons are 20 or 30 fathoms deep. In view of these general considerations, it may be repeated that a long-continued stability of reef foundations is not a necessity for the production of lagoons with smooth floors and roughly accordant depths. Rough accordance of depths obtains even when lagoons in a region of instability are included, and therefore the postulated stability of the central Pacific is not proved by such accordance.

Moreover, it is not to be overlooked that certain lagoons in various parts of the Pacific are in part at least unusually deep, as if their foundations had been characterized by exceptionally active and recent subsidence. Thus Viti Levu, the largest island of the Fiji group, which is believed on independent evidence to have suffered a modern tilting to the northwest, has an extensive and imperfectly enclosed lagoon floor or submarine bank on the northwest side, with depths increasing gradu-

ally to 58 fathoms near the end of the partly submerged barrier reef, and with two soundings of 80 fathoms farther off shore where no reef has grown up. Again, the great lagoon of the Exploring Isles in eastern Fiji, where independent evidence of recent eastward tilting is found, has depths increasing eastward to 70 and 80 or more fathoms. Two soundings of 50 fathoms on the narrow Thikombia bank in northeastern Fiji also deserve mention, for such depths are exceptional on small banks. The unusual lagoon depth of 59 fathoms back of the "sunken barrier" of eastern New Guinea, as above stated: the exceptional depth of 70 fathoms in the barrier-reef lagoon of Vanikoro in the Santa Cruz group; the depths of 60 or more fathoms on the bank that surrounds the Samoan island of Tutuila; the depth of 55 fathoms in the little Clipperton atoll, only two miles in diameter, in the eastern Pacific, of which further mention is made below; the depths of 60 and 70 fathoms on great Saya de Malha bank in the southern Indian ocean; the depths of 50, 60 and 70 fathoms or more on the unrimmed bank that surrounds the small island of Fauro in the the northwestern part of the Solomon group; the depths of 50 or 60 fathoms on the bank rimmed by a submerged reef along the northwestern side of Palawan, the long, southwesternmost member of the Philippine group; and the depths of 50 or 60 fathoms in the Macclesfield bank, a large "drowned atoll" of the China sea—all these appear to be additional cases of relatively active and recent subsidence. Hence if these exceptional lagoon and bank depths are, as the advocates of the Glacial-control theory would probably admit, determined by a fairly active subsidence of recent date which could not be altogether compensated by aggradation, a slower subsidence may be regarded as having been better compensated in lagoons of more ordinary depth. This is especially true in examples where a submergence of more than 50 fathoms is indicated by the forms of the partly submerged valleys, as in Tahiti, Borabora, and other members of the Society group; in Kandavu and other members of the Fiji group; in New Caledonia; and elsewhere.

In any case, the moderate and fairly accordant depths of reef-enclosed lagoons in regions of subsidence need not occasion surprise; for the very presence of reefs around the lagoons shows that whatever relative changes of level have taken place in ocean surface and reef foundations, the changes cannot have been faster than the slow rate of reef upgrowth; and if reefs have been able to maintain themselves at sea level by upgrowth during such changes of level, lagoon floors may have maintained by aggradation a moderate depth appropriate to their area during the same changes. This aspect of the problem need not be pursued further here.

Evidence of Tagula and Its Satellites against Abrasion.—However probable the assumption of low-level platforms of abrasion may be for islands near the margin of the coral seas where the Glacial cooling of the ocean waters may have inhibited coral growth, it is extremely improbable for Tagula, which lies not far from the equator in the western and therefore warmest part of the Pacific. The presence or absence of an abraded platform around Tagula cannot, however, be so well settled by a general estimate of such probabilities and improbabilities as by a search for the plunging spur-end cliffs that should be visible around the coasts of the main island and its satellites, if a wide platform had actually been cut across the area of the present lagoon when the ocean surface lay some 30 fathoms below its present level. The search should be made especially on those parts of the island coasts which lie nearest to the barrier reef; for there the spur ends of the mountainous islands must have been attacked and cut back at least a mile or two, while the 10- or 15-mile platform was in process of abrasion where the lagoon is broadest; and spur-end cliffs at the back of a one- or two-mile platform ought still to show their upper parts as "plunging cliffs," even after the ocean which cut them has risen 30 fathoms.

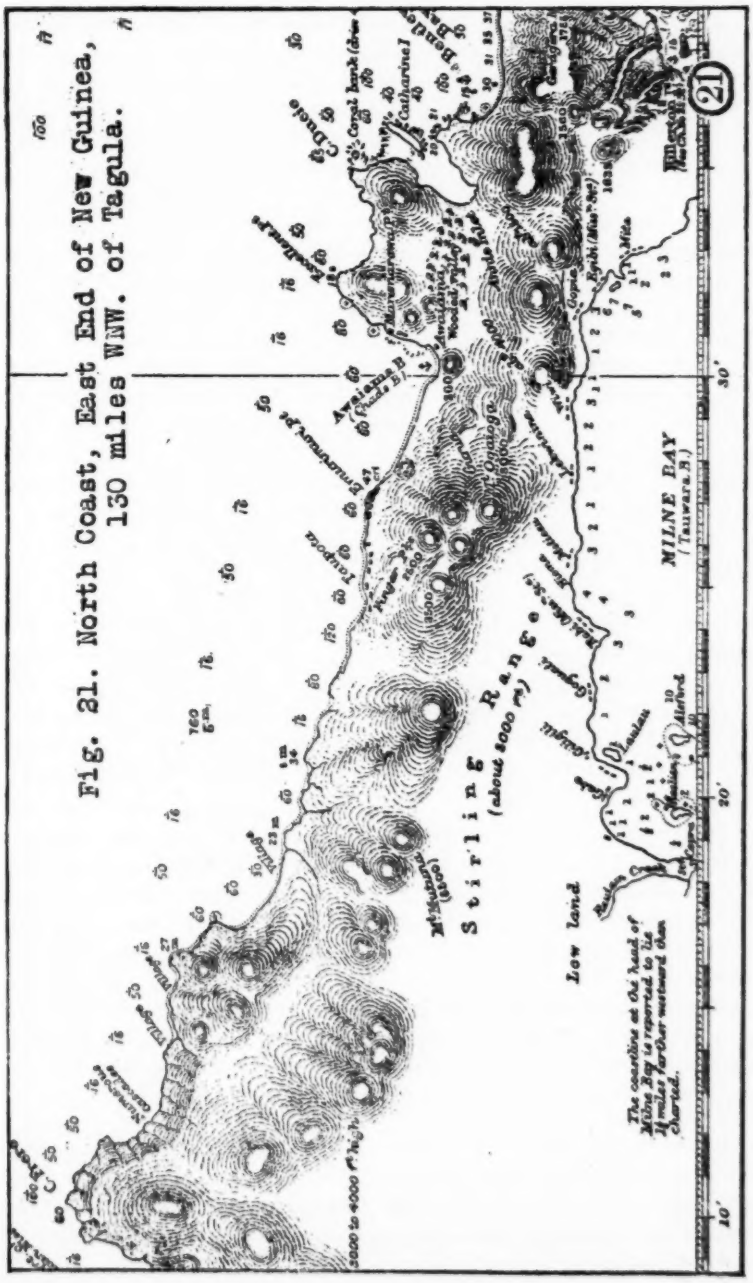
But an examination of the charts discovers no spur-end cliffs on Tagula or, with a few exceptions noted below, on any of the Calvados islands; and the absence of such cliffs, especially along the middle of the northern side of Tagula (Fig. 17) where the barrier reef is replaced by a half-mile fringing reef, militates strongly against the occurrence of an abraded rock platform beneath the great lagoon. It may be added that Rossel island also (Figs. 2, 18 and 19) gives even more emphatic testimony of the same kind; for there the barrier reef, which makes a seven-mile loop to the east and a 25-mile loop to the west, fringes the island on the northeast and on the south with deep water near by; and if a 15-mile platform were cut southwest of Tagula and west of Rossel, a platform of significant breadth should have been cut by the lowered Glacial ocean on these exposed parts of Rossel, and the cliffs at the back of such a platform should be high enough to be visible as plunging cliffs above the normal ocean level today; but no such cliffs are charted there. Thus the testimony of Tagula and Rossel against abrasion by the lowered Glacial ocean is similar to that given by many high, reef-encircled volcanic islands, as I have shown elsewhere.*

* The occasional occurrence of clift volcanic islands is pointed out in some of my earlier articles: Clift islands in the coral seas. Proc. Nat. Acad. Sci., II, 1916, 283-288. Les Falaises et les récifs coralliens de Tahiti. Ann. de Géogr., XXVII, 1918, 241–284. The coral reefs of Tutuila, Samoa. Science, LIII, 1921, 559–565.

Nearly all the islands of the Calvados chain repeat the same evidence. For example, the eastern end of Yeina, the easternmost member (Fig. 6), lies from a mile to less than half a mile from the barrier reef, outside of which a rapid descent is made to depths of over 100 fathoms; yet the chart gives no indication of shore cliffs; similarly, the northern side of Pana-tinani or Joannet island, the largest and next-to-easternmost member of the series (Figs. 12 and 13), is without cliffs, although it lies only three or four miles back of the barrier reef. If the northern compartment of the lagoon be underlaid by a platform 10 miles wide at its middle and the southern compartment be underlaid by a platform 20 miles wide, surely both Yeina and Pana-tinani should be well clift on their exposed northern sides; but they are without cliffs there.

The prevailing absence of plunging cliffs on the larger islands at least should not be ascribed to imperfect charting, for around the exposed northern side of Panniet (Fig. 3) cliffs are clearly represented. If similar cliffs were shown back of the fringing reefs of Tagula and Rossel, the case for abrasion during the lowered stand of the Glacial ocean would have support; in their absence it loses that support. Furthermore, the cliffs of Panniet plunge into deep water; soundings of from 100 to 230 fathoms are charted within 2000 feet of the shore, thus indicating a much steeper slope below sea level than that by which the visible island rises to its 700-foot summit 6000 feet inland. Hence, if the Panniet cliffs should be taken as the work of the lowered Glacial ocean, a strong Postglacial subsidence would have to be assumed in order to lower the cliff-base platform to its present considerable depth. That assumption is just as unfavorable to the Glacial-control theory as the denial of its abrasional process. Again along the northeastern coast of Misima, here reproduced in Figure 15, a cliff is well shown on the chart, and the legend is added: "Cliffs from 100 to 200 feet high;" thus indicating their exceptional nature; these cliffs may be the face of one of the elevated coral reefs mentioned by Maitland. If similar cliffs occurred on other islands they would presumably have been charted. As they are not charted, it may be believed that the islands are prevailingly not clift, and in the absence of cliffs, except for the few instances noted, it cannot be believed that Tagula and its satellites were without defense by living reefs while the ocean was lowered in the Glacial period.

Profiles of the Calvados and Other Islands.—As the foregoing descriptions of the shore features of the Calvados and other islands are based only on Admiralty Charts 2124 and 1477, it was felt desirable, although the charts bear internal indications of accuracy, that they should be supplemented by more direct evidence as to the presence or


Stirling Range
(about 8000 ft.)
Low land
MILNE BAY
(Taiwara B.)
Awaiama B.
Dinale
Corgal Bank (dries)
Catharine I.
Ogalega
Mt. Hobbs (1100)
Mt. Brown (1000)
Mt. Musgrave (1000)
Mt. Suckling (1000)
Mt. Obree (1000)
Mt. Lamont (1000)
Mt. Maguire (1000)
Mt. Victoria (1000)
Mt. Owen Stanley (13205)
Mt. Scratchley (8000)
Mt. Hercules (8000)
Mt. Knutsford (8000)
Mt. Suckling (8000)
Mt. Obree (8000)
Mt. Lamont (8000)
Mt. Maguire (8000)
Mt. Victoria (8

absence of plunging cliffs. I therefore wrote to the office of the British Admiralty in London, asking whether it was possible to secure sketches of the islands from the officers who had made the surveys on which the charts are based; and in reply was given the address of Admiral Sir Mostyn Field, who while holding the rank of Lieutenant Commander in the Royal Navy was in charge of the surveying ship "Dart" when the survey of the Louisiade group was made in 1887-88, and who was kind enough to send me a number of leaves from his sketch book containing carefully drawn profiles of a large number of islands, as seen from stations on island summits in the Calvados chain. The positions of these stations are shown by small circles in Figure 1. They are situated on the islands of Gulewa (west), Maturina, Bobo-eina (this island is included in Figure 10), and Abaga-gaheia (east). The profiles, a number of which are here reproduced in Figure 23, leave no doubt whatever that, with the few exceptions to be noted, the islands of the Calvados chain and nearly all of the outpost islands are not cliff, and thus make it altogether unreasonable to assume that the present lagoon is underlaid by a platform of abrasion. Had such a platform been cut by the ocean waves, there is no ground for imagining that wave work should continue 10 or 20 miles and then stop just short of cliffing the islands of the Calvados chain, to say nothing of the outposts. Thus an essential postulate of the Glacial-control theory and an essential process that follows from it—the inhibition of reef growth during Glacial epochs, and the abrasion of platforms at a standard depth by the lowered Glacial ocean—cannot apply to the Tagula reef-system. However that great barrier reef was formed, its broad lagoon floor must be explained without the aid of a smoothly abraded underlying platform.

This conclusion agrees with the results gained from the study of several Fiji islands, which, although bordered by fringing reefs along certain stretches of their shore line, have no plunging cliffs back of such reefs: witness especially the southwestern side of Viti Levu, the northeastern point (Cape Undu) and part of the southern side of Vanua Levu, and the southeastern side of Ngau. The same conclusion is further confirmed by the absence of plunging cliffs on the seaward side of a number of sub-mountainous islands that rise from the lagoon of the Great Barrier reef of Australia, although small cliffs have been cut upon them at present sea level by the lagoon waves.

Exceptional Steep-Margined Islands.—The exceptional steep-margined islands are ten in number, all of small size. They have irregular crests and are steep only near the shore. Eight of them lie just east of the middle of the Calvados chain, as shown in Profile 1-2 of

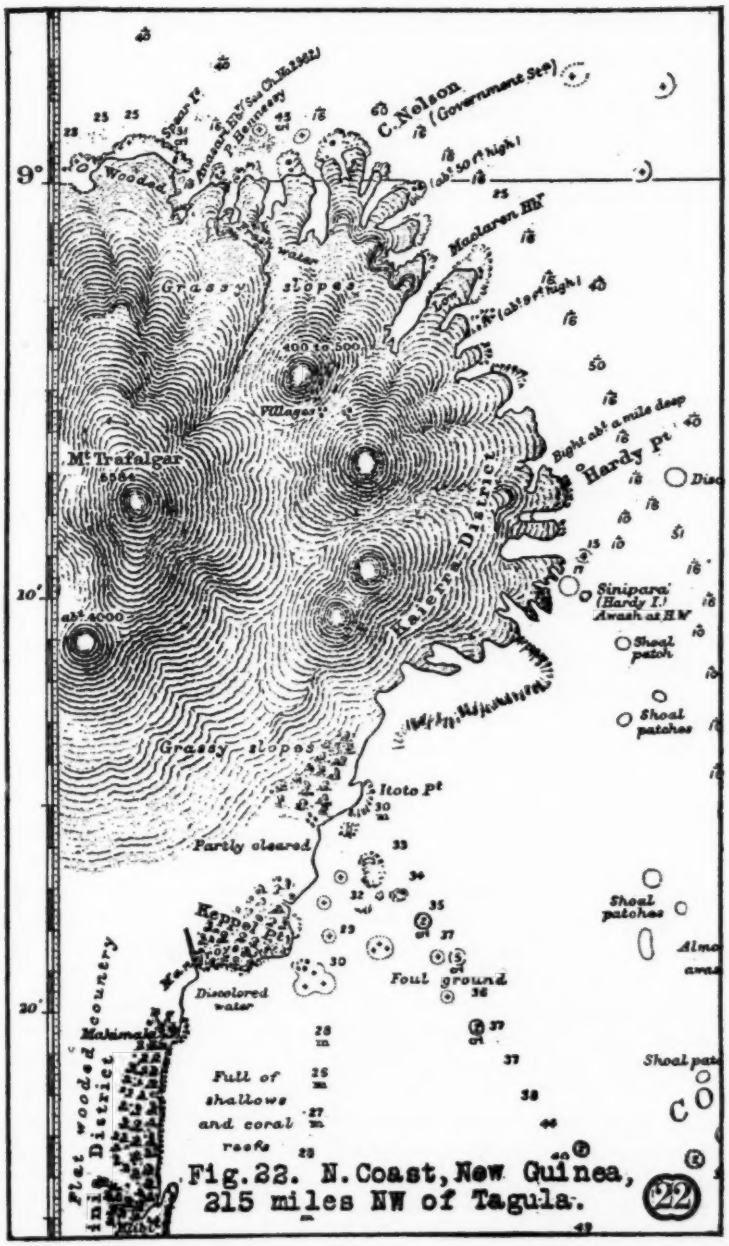


Fig. 22. N. Coast, New Guinea, 215 miles NW of Tagula.

Figure 23. Two of these, Mabneian and Panangaribu, are steep on the north; the northern reef is seven or eight miles distant. The five others of the eight, Einamu (not shown in the profiles), Panantanian (continued from Profile 1 into Profile 2), Pana Kuba, Pana-numara, and Leiga (not to be confused with an outpost of the same name in the northern part of Figure 11) are steep on the south; the southern barrier is distant about 15 miles. Gigela is a somewhat larger island not shown on the profiles here reproduced; its spurs are a little steeper than most of the others near their ends, but not so precipitous as those just named. The outlines of two islands, Bobo-eina and Bagaman, do not agree in Profiles 3 and 4; Profile 3, drawn from the nearer of two observing stations, shows the islands with sloping spurs; Profile 4, drawn on a somewhat larger scale from a more distant observing station, shows them with steep spur ends. As the nearer profile is probably the more trustworthy these two islands are not included among the clift islands.

The other two of the 10 steep-margined islands are outposts in the barrier southwest of the west end of the Calvados chain; they are Panasia or Real and Pana-vara-vara or Rugged islands; both are shown with cliffs in Profiles 5 and 6. Fortunately these are among the few islands the composition of which is reported by Maitland; they are colored on his map as consisting of "uplifted coral limestones." The first is exceptional in being represented as clift on the chart (Fig. 9); it is two miles long and 530 feet high and is described by Maitland as looking like a "raised atoll;" the other is one-half mile long and 345 feet high. The profiles of these two outposts in Admiral Field's sketches are similar to those of the other steep-margined islands above named, and dissimilar from the great majority of islands in the group, which have sloping spurs; and Panasia, like Pana-vara-vara, has a curved crest, not at all like the level crest of a raised atoll, such as Maré or Lifu in the Loyalty group north of New Caledonia. Hence, I am inclined to regard both these outposts not as atolls but as islands of some non-limestone composition, with raised barrier or fringing reefs, more or less eroded, around their flanks. In this respect they are therefore representative of what all the other Calvados islands are supposed to be, insofar as they partook of the uplift that is believed to have elevated the northwestern part of the Tagula barrier. But while most of the uplifted islands have lost their fringing-reef benches by erosion, these two outpost islands like the eight other steep-margined islands seem to have preserved enough of their uplifted reefs to give them the appearance of being clift. It would surely be most arbitrary to accept the steep slopes of those ten exceptional islands as clift by wave action during the abrasion of a low-level platform across the area of

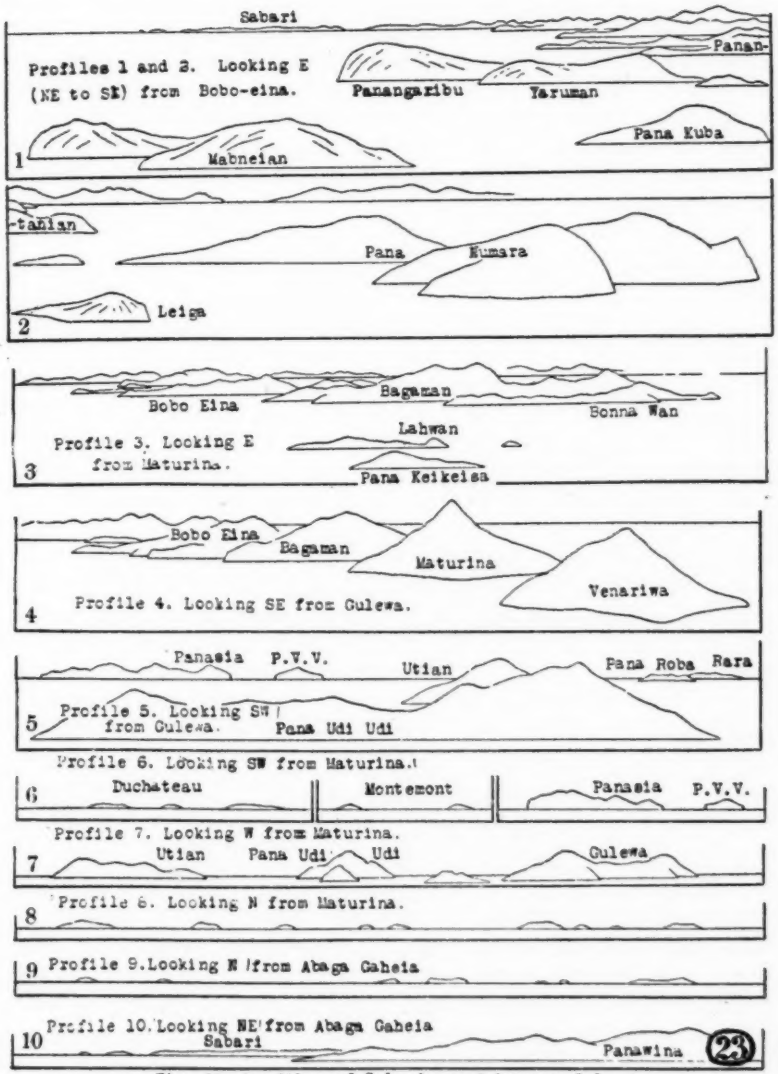


Fig. 23. Profiles of Calvados and Outpost Islands.

the present Tagula lagoon, for the great majority of the islands, some of which are in much more exposed positions than the six first named of the steep-margined islands, nevertheless testify against abrasion. Thus several examples of islands with gradually sloping spurs in the east-central part of the Calvados chain are shown in the neighborhood of the exceptional steep-margined islands in Profiles 1 and 2; others in the western part of the chain are shown in Profiles 5 and 7. The occurrence of steep-margined and gently sloping islands together in the Calvados chain favors the special explanation for the steep-margined islands given above.

Evidence of Outpost Islets against Abrasion.—The unique outpost islets of the Tagula barrier reef give even stronger evidence against abrasion than that offered by the majority of the inner islands. Had the outpost islets originally been small and unprotected by living corals during the lowered stand of the ocean in the Glacial epochs, they should, especially if they are composed of reef limestones, have been completely cut away by wave attack if it continued long enough for the abrasion of the 15-mile platform which, according to the Glacial-control theory, should underlie the broad southern compartment of the Tagula lagoon. Had the outposts been originally of larger size than now—and they must have been larger than now when the ocean was lowered—they should today present well-developed plunging cliffs on their exposed sides; but except in the cases of the two limestone islands above specified and a small outpost in Profile 9, no such cliffs are shown on the outposts on chart or profiles. Moreover, while the northern outposts exist in their present number, and still more while they existed in greater number and in greater size during the lowered stand of the Glacial ocean, it would seem impossible for the waves of the lowered ocean to abrade the ten-mile platform in the area of the northern lagoon compartment behind the outposts. The testimony of the outposts is therefore strongly against abrasion as postulated in the Glacial-control theory. It should be noted, however, that as far as the profiles of these small islets are concerned, they were all drawn from the summits of larger islands in the lagoon. Hence their exterior slope is not seen. But if effective abrasion had taken place, the ends of the outposts in the line of the barrier reef should have been cliff about as strongly as their outer sides; and the profiles show the ends to be sloping, with one exception in Profile 9. Many of the profiles are small; but if so small an islet as Pana-vara-vara is drawn carefully enough to show its cliffs, the prevailing absence of cliffs in the other profiles may be taken to prove absence of cliffs on the islets themselves.

Beginning in the southwestern part of the barrier-reef circuit, the three Duchateau islets, charted in Figure 7, are shown in Profile 6 along with the two Montemont islets which are charted in Figure 8, a little farther west. After passing around the southwestern curve of the barrier, the limestone-rimmed islets, Panasia and Pana-vara-vara, already mentioned, are encountered; they are charted in Figure 9 and drawn in Profiles 5 and 6, as already noted. Farther northeast are the little islets, Rara and Pana-roba, which, with Utian, are charted in Figure 9, and drawn in Profile 5. Utian is particularly significant because it is said by Maitland to consist of volcanic rocks and because of its embayed outline on the ocean side. Between it and Gulewa lies Pana-udi-udi, of unknown composition; this island is seen end-on in the distance in Profile 7, and in a nearer side view in Profile 5. The contrast between the sloping profiles of Utian, Pana-udi-udi, Gulewa, Pana-roba and Rara and the clift sides of Panasia and Pana-vara-vara is significant. The little outposts in the northern loops of the barrier reef, several of which are charted in Figures 10, 11 and 12, appear, with one exception, to have gentle slopes; several of them are drawn in Profiles 8 and 9. Sabari, the longest outpost, is charted in Figure 12. No exterior profile of this island is available, but its northwestern end, which ought to be clift if the lagoon floor is underlaid by an abraded platform, has a gentle slope, shown in Profiles 1 and 10; and two minute outposts near by are in line with it to the northwest. The Calvados island, Hemenahei, which lies a short distance south of Sabari, is not charted as having cliffs in Figure 12.

In view of these well certified facts of form, it seems out of the question to believe that the northern compartment of the Tagula lagoon is underlaid by an abraded platform; and if it is not, there is no sufficient reason for thinking that the southern compartment is so underlaid. This conclusion is confirmed by the non-clift margins of the slender Renard islands (Fig. 16), about 10 miles north of the Tagula barrier. They are composed of uplifted reef limestones, as above noted, and are surrounded by a fringing reef with deep water near by; they surely ought to have been clift by the lowered ocean of the Glacial period if it abraded extensive platforms elsewhere, and if reef-building corals were so weakened as not to be able to withstand the waves. But the chart of these islands shows no signs of cliffs around them.

It is true that special conditions may be imagined under which platforms may have been abraded, even if the outpost islands now rise in the enclosing barrier reef; but the conditions are so exceptional that they are unacceptable. For example, the outpost islets might be imagined to be young volcanic islands, built up after a platform had been abraded and after the reef had grown up from it; but this demands

that a considerable number of volcanic vents should conspire to arrange themselves in highly specialized positions along the platform margin. Moreover, Utian, although certified to consist of volcanic rocks, has an embayed outline strongly suggestive of elaborate dissection since its eruption; it must be much older than the reef. Again, the long and narrow Sabari outpost is, in view of its form, much more probably a remnant of an uplifted and eroded reef than a volcanic island. Finally, two outposts, Panasia and Pana-vara-vara are certified to consist at least in part of limestone; their presence indicates an uplift in this district of 100 feet or more; yet the lagoon thereabouts is of ordinary depth. Hence their uplift must have taken place before the present lagoon floor was formed. As pre-existent islands they ought, according to the Glacial-control theory, to have been largely cut away, yet each of them now possesses a slender point directed seaward. They must therefore have been as well protected by living reefs while the ocean was lowered as they are today. Thus we are again compelled to reject an important postulate and an essential process of the Glacial-control theory, as far as Tagula is concerned. However, it should be remembered that that theory may apply to islands near the margin of the coral seas, even if it does not apply to Tagula and to many other islands over the greater area of the coral seas.

Cliff Volcanic Islands Elsewhere.—In order to emphasize the contrast of the gently sloping islands of the Tagula region with the precipitous cliffs of unquestionably abraded volcanic islands, a view of Lord Howe island, received through the kind attention of Mr. E. C. Andrews, Department of Mines, Sydney, Australia, is here introduced in Figure 24. This island is a small volcanic residual which rises from a submarine bank measuring 8 by 12 miles across and from 20 to 40 fathoms deep, between New Zealand and Australia, at the margin of the present coral seas. According to the best interpretation that I can make, the bank consists of a barrier reef and its lagoon floor, which were formed in Preglacial and Interglacial times around a volcanic island, but which were truncated in the Glacial epochs when the reef-building corals were killed and the lowered ocean attacked the central island. In other words, this island and bank, like a few others in similar marginal position with respect to the coral seas, actually represent —but with two significant exceptions—the processes which, under the Glacial-control theory, are supposed to have been operative over nearly the entire extent of the coral seas. The two exceptions are that the reef foundation has probably subsided during the formation of the barrier reef; and that no reef has here grown up from the abraded platform in the present Postglacial epoch, presumably because the tempera-

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tures prevailing in this epoch are somewhat lower than those that prevailed in earlier non-Glacial epochs, especially in the last Interglacial epoch. The imposing cliffs of Lord Howe island, 600 or 800 feet in height, are therefore to be ascribed to precisely such abrasion as is assumed, under the Glacial-control theory, to have been widely operative in the coral seas; but the wide operation of this process seems inadmissible because the great majority of high islands within the barrier reefs of the coral seas are not clift. This aspect of the coral-reef problem will be dealt with in a special article on the "Marginal belts of the coral seas," to be presented to the Geological Society of America for publication in its Bulletin.

Bearing of the Tagula Lagoon on Other Lagoons.—The theory that barrier-reef and atoll lagoons are underlaid by nearly level platforms abraded around stationary islands is not based on any direct observation of the inferred platforms, for they are, of course, inaccessible in the case of sea-level reefs, and no such platforms have been discovered in the case of elevated reefs. Indeed, both the existence of abraded platforms and the still-stand of the islands around which the platforms were abraded are suppositions which appear to have been introduced into the Glacial-control scheme for theoretical reasons: First, because it was believed that the smoothness of lagoon floors is greater than could have been produced by the accumulation of sediments on uneven foundations, now subsided to a considerable depth; and second, because it was believed that the depths of lagoon floors are more nearly alike than they could be if they had been built up on subsiding foundations.

As to the second of these suppositions, it has been pointed out on an earlier page that the actual depths of many reef-enclosed lagoons vary from 10 fathoms or less to 80 fathoms or more; hence, in so far as the smaller lagoons have smooth floors, their smoothness must be due to smooth aggradation whether their rock foundation is an abraded platform at a standard moderate depth, or an uneven mountain mass at a greater depth. And it has already been noted that, by whatever theory coral reefs are explained, small reef-encircled lagoons should be as a rule shallower than large ones, for such variation of depth is a natural consequence of the fact that the waste inwashed from each linear foot of reef front will have a smaller interior area to aggrade in a small lagoon than in a large one. It is in accordance with this rule that the little reef loops in the northwestern arc of the Tagula barrier are much shallower than the two large compartments of the main lagoon; but this has no direct bearing on the theory that the reef and

the lagoon are underlaid by a flat platform cut on a still-standing foundation.

On the other hand, as to the two above-named suppositions, it appears from the facts and inferences already presented concerning the non-clift spur ends of Tagula and its satellites, and more particularly from the facts and inferences concerning the outpost islets of the Tagula barrier, that the northern compartment of this great lagoon cannot be underlaid by a platform abraded on a stationary foundation; for there is good evidence in support of the double conclusion that abrasion has not taken place and that the island has not stood still. Hence we are constrained to believe that this remarkably smooth lagoon floor has in all probability been built up by slow and long-continued aggradation during the similarly slow and equally long-continued subsidence of the uneven foundation on which the enclosing reef has its deeply submerged base, although the possibility of interruption in the regular continuation of these processes by reason of a temporary uplift of sub-recent date has been pointed out.

The presence of a smoothly abraded platform is therefore not essential to the production of this smoothly aggraded lagoon floor; and if such a platform is not essential in the northern compartment of the Tagula lagoon, which measures about 25 by 10 miles, it cannot be essential in the larger southern compartment either, or in any other lagoon in the whole breadth of the Pacific, even though the reefs which enclose such lagoons do not contain outpost islands to serve as local witnesses against the possibility of platform abrasion. But this is not all.

Both compartments of the Tagula lagoon are of normal depth, or of slightly less than normal depth, in their broader parts for lagoons of their large size; the less depths in their narrower parts, as in Figures 6, 12 and 13, and in the smaller lagoons not far away, as well as in the small lagoons of the Tagula reef loops, are also normal for lagoons of smaller size. All these normal depths occur in spite of the abundant evidence against the stability of Tagula and in favor of its long-continued subsidence of great amount, and in spite of the further evidence for the instability of the Louisiade region as a whole given by the elevated reefs of Misima and by the provisionally adopted explanation of the Tagula outposts by elevation, erosion and subsidence. Hence it is no more necessary to assume that Tagula has long been stable in order to account for the normal depth of its great lagoon than to assume that a platform has been abraded around it in order to account for the smoothness of the lagoon floor. Slow aggradation by evenly distributed sediments during the slow subsidence of an uneven foundation, possibly aided by erosion during emergence, as noted above,

should therefore be regarded as sufficient to develop the Tagula lagoon floor at an ordinary depth as well as to give it a smooth surface. If this be true for the Tagula lagoon which is situated in a region of unquestioned crustal disturbance, it may be equally true for reef-enclosed lagoons in other parts of the Pacific where crustal conditions are not so well known.

In view of the facts and inferences thus summarized, as well as in view of similar summaries of evidence previously published, the presence of smooth lagoon floors at ordinary depths appropriate to their size can not be accepted as sufficient proof of the long-continued stability of coral-reef foundations in the open Pacific, or for their abrasion to a smooth platform at a standard depth by the waves of the lowered Glacial ocean while the reef-building organisms were weakened or killed by the chilled ocean waters. And as the stability of reef foundations and their abrasion to platforms of standard depth both appear to have been assumed in the Glacial-control theory, largely because these assumptions were thought to be necessary in explaining the smoothness and the roughly accordant depths of many lagoon floors,—among which, however, the Tagula lagoon was not included—both assumptions may now be regarded as not generally necessary, although one or both of them may of course still be accepted as far as need be wherever demanded by direct evidence. Such evidence is, in my belief, afforded by certain islands near the margin of the coral seas, as will be shown in the later article already referred to.

Outpost Islets Elsewhere.—High islands of various dimensions rising from the lagoons of barrier reefs are common enough; but small and high islets rising from the reefs themselves—that is, outpost islets in the sense of that term as here used—are of rare occurrence. One of the best examples is furnished by the islets on the submerged reef that loops some six miles westward from the island of Rotuma, north of Fiji. Three outpost islets here rise to heights of 190, 860, and 1920 feet, and all appear to be volcanic, as far as they are described.[8] The highest and largest is clift on its exposed northwestern side, but the main island is not clift on its southeastern or windward side, where it is bordered only by a very narrow fringing reef. The relations of main island, outposts, and reefs here need further study. The Fiji archipelago offers only one well-marked example of an outpost islet in the atoll of Ngele Levu, the northeasternmost member of the group.

[8] J. S. Gardiner. The Geology of Rotuma, Quart. Jour. Geol. Soc., LIV, 1898, 1–11. The Coral reefs of Funafuti, Rotuma and Fiji . . . Proc. Camb. Phil. Soc., IX, 1898, 417–503.

According to Agassiz,[9] this atoll is of pear-shaped outline, measuring 14 by 7 miles, with a lagoon 10 or 15 fathoms in depth; three islets of coralliferous limestone rise from the eastern or windward arc of the reef to heights of about 60, 40 and 30 feet. It is difficult to believe that these outpost islets could have survived if the lagoon be underlaid by an abraded platform. A less marked example is afforded by the smaller reef of Wailangilala, 40 miles farther south. It is about three miles in diameter and its lagoon has depths of 22 and 23 fathoms; an islet on the eastern side of this reef has a height of 15 feet, hardly sufficient to warrant its being called an outpost; the lighthouse upon it is familiar to travelers between Fiji and Hawaii. According to Agassiz, under whose direction a boring was made here to a depth of 85 feet, the islet is not a part of the present reef, but "the fragment of an ancient island of larger size, which once covered the whole area of the lagoon;" but, if so, its survival on the windward side while a sub-lagoon platform was abraded seems impossible. Hence in both these cases, as at Tagula, abrasion by the lowered ocean must have been prevented by the presence of living corals. If these limestone outpost islets were thus protected from abrasion, all other islands in Fiji must have been similarly protected.

Cosmoledo reef, between the northern end of Madagascar and Africa, measures 9 by 6 miles, with a reef flat from one to one and a half miles wide; the enclosed lagoon is only 3 or 4 fathoms deep. Several islets with heights up to 50 feet arise from the reef flat. Not far away Aldabra island is a raised atoll so little dissected as to preserve an almost continuous rim; it measures 17 by 5 to 7 miles, with a height of 20 feet; the enclosed lagoon is either dry or very shallow. The islets on the Cosmoledo reef are therefore probably remnants of an emerged reef of earlier origin.

A typical example of a little outpost islet—a mere "rock"—is offered by the lonesome Clipperton atoll in the eastern Pacific (Lat. 10° N., Long. 109° 30′ W.), which is represented in an Admiralty chart as two miles in diameter, with a lagoon in which 65 soundings include seven with the unusual depths of 40, 48, 52, 45, 42, 40, and 55 fathoms. The small volcanic rock, 500 feet across and 62 feet high, rises from the southeastern arc of the reef, and is regarded by Wharton as a remnant which has resisted wave attack.[10] And so it may be, as it stands in a relatively cool part of the Pacific, where coral growth may have been inhibited during the Glacial period. But it may also

[9] A. Agassiz. The Fiji islands and coral reefs. Bull. Mus. Comp. Zool., XXXIII, 1899, 1–167; see p. 43–47.

[10] W. L. J. Wharton. Note on Clipperton atoll (Northern Pacific). Quart. Journ. Geol. Soc., LIV, 1898, 228, 229.

be the summit of an unsymmetrical volcanic peak, owing its present eccentric position as well as its small altitude to subsidence, as is further explained below. In any case its lagoon is so deep that a sub-lagoon platform cannot have been abraded by the lowered glacial ocean, unless subsidence has taken place since.

Aitutaki, a small volcanic island and reef in the Cook group, may be here mentioned not so much because this island, like Panniet, occupies the northern corner of the triangular reef which measures about six miles on a side, but because of Agassiz' description of it. He states that "volcanic outliers crop out at many points on the barrier reef," as if they were outpost islets, and regards the island as "an excellent example of a volcanic rock flat upon which corals are growing."[11] If the lagoon, which is only four fathoms deep, be truly underlaid by such a rock flat, the flat cannot have been produced by abrasion if the rocks seen "at many points" in the reef are properly described as volcanic outcrops; while they survive, the space within them could not have been attacked by the waves; but further observation of this example is desirable.

ANOTHER LESSON FROM THE TAGULA OUTPOST ISLETS.—It may be conceived that coral reefs grow up vertically from their foundations, so as to maintain the outline and the perimeter of their lagoon unchanged; or that they grow upward and outward, so as to increase the perimeter of their lagoon; or upward and inward, so as to decrease it. This aspect of the coral-reef problem has been discussed in one of my earlier papers,[12] with the conclusion that outward upgrowth is possible around very slowly subsiding foundations, especially if the adjoining ocean be of moderate depth; but that inward upgrowth must take place from foundations that subside more rapidly, especially in a deep ocean. Several of the Tagula outposts, which are believed as already explained to represent the diminished summits of small residual islets composed of elevated reef limestone, favor the latter conclusion for the following reasons: Most of these outposts stand in excentric positions with respect to their reef loops, and in a good number of cases they are so far excentric that they rise from the reefs themselves instead of from the little lagoons that the reefs enclose. Thus they are outpost or excentric islets in a double sense; they not only rise in the general course of the great barrier reef outside of the Tagula lagoon, but many of them rise from the reefs of the small loops which make up the north-

[11] A. Agassiz. The coral reefs of the tropical Pacific. Mem. Mus. Comp. Zool., XXVIII, 1903; see p. 170.

[12] Extinguished and resurgent coral reefs. Proc. Nat. Acad. Sci., II, 1916, 466-471.

western arc of the great barrier. The outpost summits could not be contained in the reefs if the reefs had been formed by outward upgrowth from a lower and therefore larger contour line on the submarine slope of the outpost islet. Even after vertical upgrowth a reef could not include an islet summit unless it had an overhanging face on one side, and that is altogether improbable. Nor should an excentric position of an outpost result if its submarine slopes had the form of a symmetrical cone, from which a reef loop was formed by inward upgrowth.

But if an original outpost islet had an unsymmetrical form and an excentric summit, with a much steeper slope on one side than on the other, then a part of a reef formed by inward upgrowth might cling to the steeper slope and eventually include the excentric summit, while the rest of the reef formed by inward upgrowth from the gentler slope would enclose a diminishing lagoon. Hence at least some of the reefs in the loops of the northwestern arc of the Tagula barrier have probably been formed by inward upgrowth. The same is probably true of the wide fringing reef around the Renard islands (Fig. 16), where some minute islets rise from the outer margin of the reef; and also of the barrier reefs which become fringes on the northern side of Tagula itself (Figs. 6 and 17), and on the northeastern and southern sides of Rossel (Figs. 2, 18 and 19). Similarly the excentric position of the outpost rock in Clipperton atoll, above mentioned as standing alone in the eastern Pacific, is like that of the Tagula outposts well explained by the inward upgrowth of its reef from the submarine slopes of an unsymmetrical island, now mostly submerged.

Tagula Supports Darwin's Theory of Coral Reefs.—It appears from the foregoing account that Tagula with its satellites and outposts gives much better support to Darwin's theory of coral reefs than to the Glacial-control theory. Unlike the scattered volcanic islands of the central Pacific, which have each been formed separately and independently of one another, the various islands of the Louisiade group are not of separate origin, but are related parts of a long mountain system; and as such the evidence that they furnish of crustal deformation, advanced erosion, and strong regional subsidence seems well established. On the other hand, as they give no evidence of having been significantly modified by abrasion, it appears reasonable to suppose that they have been continuously encircled by defending coral reefs during their subsidence. Hence the Tagula barrier reef is best explained by long lasting upgrowth, and the lagoon floor by long lasting aggradation, modified by recent uplift, erosion and subsidence, as above proposed; both the reef and the lagoon deposits being presumably based on the uneven

surface of the subsided mountain range. The subsidence of the region may well have been intermittent, and the ocean surface may very presumably have suffered Glacial changes of level during the later phases of the subsidence; but the reefs around Tagula, as well as around Rossel and Deboyne, give no visible indication of having suffered abrasion during a time of inhibited coral growth at any stage in their long existence.

It must be inferred, however, that in the southeastern arc of the Tagula barrier, where no recent uplift is indicated, reef upgrowth may have been temporarily interrupted if the lowering of the ocean surface in the Glacial epochs took place at a faster rate than the subsidence of that part of the reef foundation at those times, thus leaving the crown of the reef emerged. It must also be inferred that if emergence of the reef were thus caused, the reef-building organisms would have transferred their belt of growth from the outer side of the reef crown to zones farther and farther down the exterior slope of the reef. This seems reasonable, because during the lowering of the ocean surface, the waves would have progressively removed the loose fragmental and detrital material that normally accumulates on the reef slope below depths of 15 or 20 fathoms, and would have thus prepared a firm surface for the reef-building organisms to grow upon.

Similarly, it must be inferred that at each Interglacial epoch of rising ocean level, the reef-building organisms must have shifted their belt of growth upwards toward the former reef crown, and that as they ascended the slope they must have repaired the erosional damage suffered by the reef during its emergence; and that during each slow rise of the ocean surface, detrital material would accumulate on the exterior slope of the reef at depths below 15 or 20 fathoms, where corals had been growing while the ocean was lowered, and would thus tend to reconstitute the characteristic declivity by which most reefs descend into the deep sea; namely a declivity having a fairly strong slope to the moderate depth of about 40 fathoms where wave action is ineffective, followed by a steeper pitch to greater depths. Yet, probable as these changes of ocean level are, and reasonable as the inferences concerning the accompanying changes in organic conditions seem to be, no direct indication of their occurrence has yet been found. It is as if a moderate and recent subsidence of the region had lowered all records of the Glacial period to depths where they cannot be detected. In any case these records appear to have been subordinate to those consequent upon long-continued and great crustal subsidence.

The argument by which the above conclusion in favor of Darwin's theory has been reached is by no means infallible; it needs confirmation by a critical observation of Tagula, its satellites and outposts;

but in the meantime its validity seems to me highly probable. Let it be understood, however, that Darwin's theory does not postulate that all subsiding islands have subsided at a uniformly slow rate, so as always to permit the upgrowth of coral reefs from them; still less that all islands have subsided. The original theory postulates only that, where barrier reefs and atolls exist, the subsidence of their foundations has not been so fast that it could not be compensated by reef upgrowth and to a less degree by lagoon aggradation. The theory should be amended today so as to postulate that, where barrier reefs and atolls exist, the subsidence of their foundation together with any rise of ocean level that has taken place during the subsidence, has not caused a submergence so rapid that it could not be compensated by growth of the reef and the aggradation of the lagoons; but as far as Tagula is concerned, changes of ocean level do not seem to have caused any great modification in the form of the reef system from that which it would have if subsidence had taken place in an ocean of unchanging level.

On the other hand, the present barrier reefs of the Louisiade group should not be regarded as uninterrupted upgrowths from the original shore line of a continuous New Guinea-Louisiade mountain range before subsidence of the region began; for in that case the reefs should be as continuous now as the shore line was then, instead of now being resolved into separate barriers around the separate islands. When subsidence began, an initial reef presumably grew up from the original shore line, first as a continuous fringe, except for breaks near stream mouths; then as an equally continuous barrier, except for interruptions at passes. But in time the first generated reef was probably drowned by an unusually strong subsidence, and thereupon fringing reefs of a second generation, of less total perimeter than before, would, according to a special condition of Darwin's theory quoted below, be established around the new shore line. Such an extinction of barrier reefs, followed by a new generation of fringing reefs at a higher level, may have taken place several times, especially in the eastern part of the mountain system, where subsidence appears to have been greater than in the western part; and after each time of such reef extinction, the perimeter of the new reefs and the area included within them must have been smaller than before. Moreover, when subsidence submerged some of the passes in the mountain crest, the continuous shore line of the original mountain system must have been converted into several separate or independent shore lines around the separated culminating parts of the system between the submerged passes; and each such part would thereupon become an island. Any later subsidences that were strong enough to drown the reefs would result in the still further separation of the independent islands and reefs. The present arrangement of

well-separated barrier reefs around the farther separated islands of the Louisiade group has probably resulted from some such sequence of changes.

CONFIRMATION BY POCKLINGTON REEF.—Fortunately, the sequence of changes thus sketched is not left altogether to the imagination. The Louisiade region itself affords fairly direct evidence of precisely such a change as has been supposed; that is, of so rapid a subsidence in its eastern part that reef upgrowth could not keep pace with it. It has already been stated that all the larger islands are composed of steeply inclined and greatly eroded schists and slates, and that rocks of a similar character occur in the mountains along the northern coast of eastern New Guinea. In view of these facts it is generally believed by all writers on the subject that the mountain system to which the Louisiade islands as well as the New Guinea ranges genetically belong originally extended to the east of Rossel, the farthest island now visible. This belief is sufficiently grounded in the fact that the rock structures of Rossel appear to be about as massive and as much disturbed and as deeply eroded as those of the islands farther west. Hence the mountain system must have been originally prolonged beyond the outermost island; just as the deformation by which the ancient mountain ranges of Brittany or of southern Ireland were produced and the subaerial erosion by which they were shaped must have originally extended into the Atlantic area much farther westward than the now visible peninsular ends of the ranges. It is therefore reasonable to conclude that the New Guinea mountain system as a whole once extended scores or hundreds of miles farther eastward than Rossel; that its western part, although having had ups and downs in its history, today forms a continuous mountain range in eastern New Guinea, because subsidence has not been dominant there; that an intermediate discontinuous part characterized by strong subsidence is now seen in the Louisiade archipelago, where, with the exception of Misima, the mountain range was, during the later stages of subsidence at least, depressed so slowly that compensating reef growth was possible; but that the easternmost part, now completely submerged, was during the later stages of subsidence, if not earlier, depressed either so greatly that it is now surmounted only by atolls, or so rapidly that no reefs could grow up to sea level from it. It is therefore especially interesting to learn that an atoll, Pocklington reef, 18 miles long and three wide, lies 100 miles eastward from Rossel. According to the British Admiralty Sailing Directions for the Pacific, Volume 1, the wreck of a large iron ship lay on the south side of the atoll in 1880. Soundings in this completely submerged part of the mountain system would be of special interest in connection with the

coral-reef problem. It is evident that submerged reefs as well as submerged mountain-top islands may here await discovery.

The Peculiar Case of Misima.—It should not be forgotten in this connection that, as already intimated, Misima (Fig. 4) affords evidence in its unconformable reef terraces of having subsided at times too rapidly for compensation by reef upgrowth, and thus gives good warrant for accepting not only the occasional rapid subsidence of Tagula and its neighbors as noted above, but also the rapid and greater subsidence and complete disappearance of the lost easternmost part of the New Guinea mountain chain, as just described. The unconformable reefs, high on the slopes of the mountains in eastern New Guinea teach the same lesson; and all these examples serve to correct the misapprehension, sometimes encountered, that Darwin's theory of coral reefs postulated a subsidence of islands no faster than reef upgrowth. As a matter of fact his theory was based on no such limited postulate. He recognized clearly that subsidence might be either slow or rapid; that existing reefs appear to have grown up where the subsidence has been so slow as not to drown them, and that reefs would be drowned if subsidence took place rapidly. The now elevated reefs of Misima are particularly pertinent here, for in so far as they were formed during pauses in a rapid subsidence preceding the recent emergence of the island, they, as well as certain sea-level fringing reefs, exemplify a type of reef formation in association with rapid subsidence that was clearly recognized as a possibility by Darwin, although he found no examples to verify its actual occurrence, as may be now pointed out.

The general understanding of Darwin's theory associates most fringing reefs with stationary or rising coasts, and there are undoubtedly many fringing reefs on coasts of those kinds; but the original statement of the theory contains the following significant passage: "If during the prolonged subsidence of a shore, coral-reefs grew for the first time on it, or if an old barrier reef were destroyed and submerged, and new reefs became attached to the land, these would necessarily at first belong to the fringing class."[13] Many fringing reefs in the Philippine islands appear, as I have elsewhere pointed out,[14] to have been thus formed, for they rest unconformably on the strongly eroded rocks of well-embayed shore lines. Although Darwin did not perceive the bearing of embayed shore lines or of unconformable reef contacts, these examples very clearly illustrate his idea that fringing reefs must be the first to form on a rapidly submerged coast, which during earlier and slower subsidence had been fronted by a barrier reef.

[13] C. Darwin. The Structure and Distribution of coral reefs, 1842, 124.

[14] Fringing reefs of the Philippine islands, Proc. Nat. Acad. Sci. IV, 1918, 197–204.

In the case of Misima, even if all of its unconformable terracing reefs were formed during pauses in emergence, the highest reef must have been formed during the pause that separated a preceding rapid and great subsidence from a following intermittent upheaval; that is, it must have been formed under the conditions specified by Darwin in the above citation. As already noted, the embayed shore line of Misima (Fig. 14) shows that its recent emergence is not so great as its previous submergence. This peculiar island is therefore in a sense intermediate between Tagula, Rossel and Panniet, on the one hand, as these islands are believed to have suffered on the whole a long-continued subsidence usually at so slow a rate as to develop large barrier reefs around extensive lagoons; and on the other hand the imagined easternmost original members of the Louisiade group which are believed to have subsided so fast that they have completely disappeared, leaving only a single atoll as a monument of their former existence.

The embayed but almost reefless northern coast of eastern New Guinea, as illustrated in Figures 21 and 22, is an excellent illustration of Darwin's principle that on a subsided coast the new reefs should be at first attached to the land, and should therefore necessarily belong to the fringing class. Not only so; that coast must also be regarded as one which has subsided rapidly because it is not fronted by an offshore barrier reef, and furthermore as one that has subsided lately because its fringing reefs of a new generation, as they may be called, are still extremely narrow. By far the greatest part of the coast in Figure 21 has no chartable fringing reef. Moresby reports that for 25 miles west of East cape, the coast is "washed by a grand, clear, reefless sea; a ship might literally sail with her sides rubbing against the coral wall which binds the shore, and find good anchorage in any of the bays where a breach is seen."[15] Farther northwest fringes of a significant breadth are developed on some of the sloping headlands around the embayed shore line of Mt. Trafalgar (Fig. 22), but other headlands have no reefs. The latest change of level by which the present configuration of this coast has been determined cannot therefore have been alone the Postglacial rise of sea level; for in that case the reefs should surely have been well formed, and they might well have included off-shore barriers as well as on-shore fringes; the latest change must have been a relatively rapid and very recent subsidence of the coast itself.

To return to the case of Misima: The absence of cliffs around the greater part of that mountainous island is peculiar. If it had been stable and had been as free from protecting reefs during the Glacial

[15] J. Moresby. Recent discoveries in the southeastern part of New Guinea. Proc. Roy. Geogr. Soc., XVIII, 1873, 22–31, see p. 28.

period as it is now, its entire coast should have been cut back, and should today be bordered by plunging cliffs. Its freedom from cliffs, except along the northeast side where the cliffs are probably those of an emerged reef, indicates that it cannot have been in its present unprotected condition during the last Glacial epoch; it must then have stood lower, so as to be protected by the now emerged reefs, or higher, so as to be protected by now submerged reefs. Conversely, the plunging cliffs on the northern, unprotected side of Panniet (Fig. 3) suggest that, if the cliffs are wave cut, the island must have sunk since they were cut, for they do not descend to a shallow platform. Close study of these islands should yield interesting results.

The Value of a Single Example.—The chief interest attaching to Tagula in connection with the coral-reef problem comes from the evidence that it gives to the effect that its great barrier reef and broad lagoon floor have been formed by upgrowth and aggradation during the slow and probably intermittent subsidence of an uneven foundation; that the oscillations of ocean level and changes of ocean temperature during the Glacial period have left no recognizable marks on the islands or in the reef system; and that the broad lagoon floor within the reef has been aggraded to a standard depth without the aid of the special conditions and processes that are invoked in the Glacial-control theory. If the Tagula reef and lagoon floor have been formed in this way, many other reefs and lagoon floors may have a similar origin. Thus Tagula may be regarded as an important witness in the coral reef problem: but it does not stand alone. The evidence offered in the present paper on Tagula and its reef merely repeats and extends the evidence presented in several earlier papers on various members of the Fiji group, Tahiti in the Society group, New Caledonia, and the Great Barrier Reef of northeastern Australia.[16] It may be added that in Foye's recent study of Fiji he also was "unable to discover in these islands any evidence of Pleistocene wave-cut platforms;" and he was led to conclude that "the detailed history of the islands of Fiji shows that they have not been stable during recent geological time, and an adaptation of

[16] Problems associated with the origin of coral reefs. Sci. Monthly, II, 1916, 313-333, 479–501, 537–572.

Les falaises et les récifs coralliens de Tahiti. Ann. de Géogr., XXVII, 1918, 241–284.

Subsidence of reef-encircled islands, Bull. Geol. Soc. Amer. XXIX, 1918, 489–574.

The Great Barrier reef of Australia. Amer. Journ. Sci., XLIV, 1917, 339-359.

Coral reefs and submarine banks. Journ. Geol., XXVI, 1918, 198–223, 289–309, 385–411.

The islands and coral reefs of Fiji. Geogr. Journ, LV, 1920, 34–45, 200–220, 377–388.

Darwin's theory may apply to many of these islands."[17] The small outpost islets of the Tagula reef are evidently of especial significance in the argument above presented, and should be closely examined as to structure and form by any observer who has the good fortune to visit this remarkable reef system.

If the solution of the coral-reef problem depended chiefly on a study of coral reefs themselves, the importance of the individual study of different reefs would not be very great, because after the several classes into which they fall are recognized, sea-level reefs do not teach much from a geological point of view, however interesting they are zoologically. It is for this reason that the examination of atolls, except by deep borings, has been unproductive, so far as the demonstration of their origin is concerned. All the facts that they offer are explained with about equal competence by various coral-reef theories, if the postulated conditions and processes of the theories are accepted. The real question at issue, however, is not whether the conditions and processes postulated in various theories are competent to produce coral reefs, but whether those postulated conditions and processes correctly represent the invisible past facts of geological history. This question cannot be answered by a study of the reefs alone; the answer is difficult enough to find when all accessible facts regarding reef-encircled islands and reef-fronted coasts are also taken into consideration. Moreover, the conditions and processes that have possibly been involved in the formation of coral reefs are so varied that nothing less than a detailed geological examination of the islands and coasts which they border will suffice to determine what conditions and processes have been actually involved in the production of any individual reef.

This is, of course, as true for the Glacial-control theory as for Darwin's theory of coral reefs. Each theory leads to the expectation that reef-encircled islands as well as the reefs that encircle them may have various forms; and in view of the evidence furnished by Tagula as to the possible formation of an extensive flat-floored lagoon at a normal depth on a subsiding foundation without the aid of abrasion, it becomes all the more necessary to review the testimony of other islands that reefs encircle, instead of basing conclusions largely upon the form and depth of the lagoon floors that the reefs enclose. The testimony of islands near the margin of the coral seas is, as has already been noted, particularly important in this connection; and those islands will be examined elsewhere. In the meantime, the evidence here presented from the marvellous barrier reef of Tagula is believed to be worthy of special consideration by students of coral-reef origins.

[17] W. G. Foye. Geological Observations in Fiji. Proc. Amer. Acad. Arts and Sci., LIV, 1918, 1–145; see page 95.

TITLES AND ABSTRACTS OF PAPERS

WASHINGTON, 1921

Ellen Churchill Semple.

Presidential Address:—The Influence of Geographic Conditions Upon Current Mediterranean Stock-Raising.

Oscar S. Adams (Introduced by William Bowie).

The Problem of Representing the Earth's Surface on a Map.

The fundamental difficulty that we encounter in our attempts to make a plane map of the earth's surface is due to the fact that the shape of the earth is approximately that of a sphere and that a spherical or ellipsoidal surface cannot be spread out into a plane without stretching, tearing, or folding. In the map we must therefore expect distortions of shape or size and in many maps both are present. We often deceive ourselves by expecting that any map whatever ought to show us any quality that we may desire to know. It is necessary to realize that a map is merely a means by which we strive to picture things that cannot be exactly pictured on a plane surface.

If the area represented is small, the distortions may be less than we could detect by any measurements, and hence such maps may be considered accurate in all respects. When the area becomes extensive, it is necessary to be careful not to accept appearance for truth. We should always consider what the map is intended to show before passing judgment regarding any particular feature of the region represented.

The possibility of representing extensive regions on a map was illustrated by a number of slides, these also illustrating the limitations that should be expected in various types of maps.

Oliver E. Baker.

Significant Changes in the Utilization of Agricultural Land as Shown by the 1920 Census.

The statistics now available from the 1920 census show significant changes in the utilization of land during the decade. There was an increase in farm land of 84 million acres in the western half of the country, where arid and semi-arid lands of the public domain were being occupied under the Enlarged and Stock Raising Homestead acts, and a decrease of five to seven million acres in the humid eastern half of the country. At the same time the crop land in the eastern states increased 34 million acres. Since the eastern half of the country contributes 90 per cent of our agricultural products, it is evident that the increased production during the decade was secured by more intensive

utilization of the existing farm land and not, as heretofore, mostly by expansion of the agricultural area.

We have reached the stage in our agricultural development when there is practically no more good or even fair land left unutilized for farming. Although our improved land amounts to only 27 per cent of the land area, the land which remains unimproved is, with few exceptions, too wet or dry, too steep or stony or infertile, for the profitable production of crops without amelioration. The population of the United States is rapidly increasing, and this increasing demand for foods and fibres cannot for long be supplied by increasing the intensity of cultivation. The diminishing returns per unit of labor applied will soon enforce recourse to the less available land. The amount of such land, which it is possible by various means of amelioration to bring into use for crops, is probably over 300 million acres. It includes about 75 million acres of drainable and probably 30 million acres of irrigable land, perhaps some 175 million acres of forest and cut-over lands not requiring drainage, but in many cases deficient in fertility, and a considerable area of stony or infertile pasture land in the East and potential dry-farming land in the West.

Whether this nation will embark upon a vast enterprise of land reclamation, or whether it will depend on other countries, particularly the tropics, to meet the demands of an increasing population, for agricultural products, will soon become a pressing national problem. If, after mature consideration, it appears advisable to embark upon a policy of protection of agricultural industries, it is important that the expansion of the agricultural area be promoted in accordance with broad plans of national scope, prepared only after a careful survey of the land resources of the nation, and based on the principle of the welfare of the whole people.

Louis A. Bauer and J. P. Ault.

Some Results of the Recent Cruise of the *Carnegie*, 1919-1921.

The magnetic-survey vessel, the *Carnegie*, completed on November 10, 1921, at Washington, D. C., a two-years' cruise, the aggregate length of which was 73,750 statute miles, the second author having been continuously in command.

The general results of the observations made on board the vessel, pertaining to terrestrial magnetism, atmospheric electricity, atmospheric refraction, oceanography, and geography, were set forth briefly and illustrated by lantern slides.

Upon the arrival of the vessel at Balboa, Canal Zone, last October, the first author, as director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, joined the vessel and

remained with her for the balance of the cruise. During the passage from Colon to Washington, special observations and tests were made of the instrumental appliances. It was once more found that with the instrumental appliances and methods used aboard the *Carnegie,* it is possible to determine the magnetic elements at sea, with all requisite accuracy, even during unfavorable conditions of sea.

Concluding tests in Chesapeake Bay again showed the absence of any deviation corrections on board the *Carnegie.*

E. B. Branson (Introduced by H. H. Barrows).

Geography of Eastern Costa Rica.

Eastern Costa Rica is a low lying coastal plain, bounded on the west by volcanic mountains ranging from 2,000 to 11,500 feet in height. The temperature varies little from month to month. The rainfall is rather evenly distributed and averages about 125 inches. The strongest wind is little more than a breeze.

The interior of Costa Rica is in communication with the eastern part only by way of a railroad through the Reventazon valley. The inhabitants and industries of the interior are sharply contrasted with those of the eastern part. The people are about 90 per cent unmixed Spanish, and the main industries are the raising of coffee and sugar cane.

The inhabitants of eastern Costa Rica are about 90 per cent Jamaican negroes, 5 per cent native Costa Ricans and immigrants from other parts of Central America, 3 per cent English, Germans, and Chinese, and 2 per cent Americans.

The chief industry is banana raising, and all the other industries of the region are dependent, directly or indirectly, on bananas.

Banana blight has killed the banana plants in some areas and these have been planted to cocoa or cocoanuts. Sugar cane does not produce well. Experiments in cotton raising have not been successful. Balsa grows rapidly and large numbers of young trees have been set out.

Robert M. Brown.

City Growth and City Advertising.

A discussion of the causes of growth of American cities with an analysis of the 100 cities showing the largest percentage of gain since 1910. An attempt is made to classify by types the advertising campaigns of cities, to indicate the economic types and wasteful types, and to correlate advertising with actual increase of population.

O. F. Cook.

Peru as a Center of Domestication.

The primitive civilizations of America were an indigenous development, since they were based on native American plants. The Peruvian

region was the chief center of domestication in America, as shown by the large number of plants that were cultivated, estimated at 70 species. About half of these are strictly endemic species, grown mostly at the higher altitudes, while the cultivated plants of the lower valleys of Peru were also the chief basis of agriculture in other parts of America. A study of the native names of cultivated plants in Peru indicates that all of the principal lowland crop plants of other regions were known to the ancient Peruvians before the Spanish conquest. Not only maize, beans, squashes, peppers and peanuts, but cassava, sweet potatoes, yautias and several other root-crops were grown in the Peruvian region, and may have originated there. A list of the native plant names and other facts indicate a primary development of agriculture in the Peruvian region. Only a few plants were cultivated in other parts of America, but not known in Peru, the principal examples being cacao in Central America and the pulque agave in the tablelands of Mexico. These domestications appear strictly secondary and incidental to the use of maize as the principal crop.

W. M. Davis.

The Barrier Reef of Tagula, New Guinea—Printed in full herewith.

Nevin M. Fenneman. (By permission of the Director of the U. S. Geological Survey.)

Certain Features of Arid Region Topography.

Tendency of gullies of drains to expand with flat bottoms, vertical sides and no tributaries. Reasons for this tendency. Its relation to wider spread horizontal stripping with little or no down cutting. Production of vertical sided mesas and reasons for coarse texture drainage pattern on semi-arid plains.

A proposed Alteration in the Physiographic Map of the United States.

J. Paul Goode.

The American Need for Authority on Fixing the Form of Foreign Geographic Names.

E. S. Gregg (By Invitation of Council).

The Influence of Geographic Factors on Ocean Shipping.

The distribution of natural resources and the state of economic development of a country determine the volume and the character of its trade, and consequently, its steamship services. The United States is rich in natural resources and has reached a high state of industrial development. As a result, the outward volume of its trade is three times the inward volume, if bulk oil, which moves in specialized vessels, is excluded. An analysis shows the imports exclusive of oil and exports

exclusive of coal, grain, cotton, and lumber make a fairly well-balanced trade; which points to the conclusion that the United States does not need a merchant marine large enough to carry 50 per cent of its total trade, but 50 per cent of its manufactured and semi-manufactured articles. A study of the leading maritime countries shows that a country rich in natural resources does not develop a large merchant marine because exploiting its natural resources is more profitable than performing an international service such as shipping. On the other hand, countries meagerly endowed with natural resources are forced into foreign trade and collateral services.

Roland M. Harper.

Some Regions in the United States with Stationary Population.

About one-tenth of the inhabitants of the United States are living in counties whose total population has been practically at a standstill for 25 years or more, in some cases for over 100 years. Although nearly every state has one or more such counties, they are not scattered fortuitously, but are mostly aggregated in certain natural regions. A statistical study of these regions shows that most of them have from 30 to 60 (never more than 90) inhabitants per square mile, and are characterized by fertile soils and extensive farming, with rather low yields per acre but high standards of living. The significance of this state of affairs and the advantages of residence in such regions were briefly discussed.

George D. Hubbard.

Geographic Setting of Chengtu, China.

Chengtu, a city of 600,000 to 800,000 people, is located on the rich, constantly renewed agricultural plain near the lofty youthful mountains of western Szechuan. It is over 650 miles to the nearest coast, and over 1500 miles by river to Shanghai, the port its products to other countries must use. It is 1000 miles from Hankow, the best point to reach a railroad.

Its only wheel commerce and travel are on wheelbarrows. Boats on streams and canals carry much. The real commerce is carried on poles slung on the shoulders of men.

The very fertile plain is greatly benefited by the ancient flood-control and irrigation system made possible by using the mountain streams that have built up the plain which the city occupies.

Mineral resources of the plain are soils, clays, and sands; of the bordering mountains, are lime and cement rock, coal, iron, oil, gas, marble, granite, copper, lead, zinc, silver, and gold.

By virtue of its position in the midst of the plain and the mountains with their wealth and possibilities, Chengtu is an important commer-

cial collecting and distributing point, a growing industrial city, a center of learning and art. With the coming of the railroads over her old foot-worn paths, and the modern development of surrounding resources, she will be the greatest city in all West China.

W. L. G. Joerg.

Some Observations on the Present Status of Geography in Western and Central Europe.

The paper was based on observations made in 1921, while on six months' leave of absence granted by the American Geographical Society, and ten to twelve years before, during a prior sojourn in Europe, as well as on printed sources of information. The territory covered on these two occasions included Great Britain, France, Germany, Denmark, Belgium, Holland, Switzerland, Austria, Bohemia, Hungary, Italy, and Spain. Other countries of Europe, outside of Russia and the Balkan States, were also discussed, on the basis of printed information. The paper dealt mainly with the development and status of geography at the universities and present tendencies in the subject. It has appeared in the April, 1922, *Geographical Review*.

Douglas W. Johnson.

The Battles of the Ourcq and Marne in 1814 and 1914—Read by Title.

The extent to which topography may influence military strategy and tactics is strikingly illustrated by a comparison of certain phases of Napoleon's 1814 campaign with the Allied operations of September, 1914, and later. On the same terrain there were fought, one hundred years apart in time, Battles of the Ourcq and Battles of the Marne. In both battles of the Ourcq the Germans attempted to turn the French left, and in both cases the attempt failed. In both Battles of the Marne the Germans held their opponents at bay along that barrier for a time, but in both cases the obstacle was eventually forced. Thereupon the Germans in both cases fell back behind the Aisne barrier and later fought a battle on the heights of the Chemin des Dames. There the same terrain imposed the same manoeuvers upon the contending armies to an extent which must profoundly impress the student of military geography.

Neil M. Judd (Introduced by invitation).

The National Geographic Society's Pueblo Bonito Expedition.

Pueblo Bonito is a prehistoric ruin, perhaps 1000 years old, situated in the semi-desert region of northwestern New Mexico. It is more than three acres in area. There were about 300 rooms on its ground floor; its walls were at least four stories high. Its dwellings were terraced

upward from two inner courts bordering which were 20 or more kivas —rooms utilized both as council chambers and as religious sanctuaries. The archaeology of Pueblo Bonito shows it to have been occupied throughout a considerable period, during which groups came in from other settlements to join with the Bonitians. As a result of these immigrations, culture phases distinguishable from those native to Pueblo Bonito were introduced. The Bonitians were familiar with distant peoples for, among other trade objects, they obtained shells for ornaments from the Pacific coast and live macaws (*Ara macao*) from the Valley of Mexico. They were essentially agriculturists and tilled large fields of corn, beans, squash, etc. No trace of their distinctive culture has been found elsewhere but it is to be expected that the present explorations of the National Geographic Society will connect the ancient Bonitians with other peoples who dwelt in the great plateau region of the southwestern United States in prehistoric time.

Julius Klein (Introduced by George B. Roorbach).

Geography in the Bureau of Foreign and Domestic Commerce.

C. F. Marbut.

The Soil Geography of the Northern Great Plains.

Character of the Soils of the Great Plains. Their distribution and relations to topographic, geologic, climatic, agricultural and population features. A definition of the Great Plains and of the Northern Great Plains from the point of view of Soil Character.

A Soil Map of the United States.

Exhibition and brief description of a new soil map of the United States, being prepared by the U. S. Soil Survey.

F. E. Matthes.

The Evolution of the Stepped Canyon Profile of Glaciation.

George J. Miller.

Twenty-five Years' Growth in Collegiate Geography.

To ascertain the growth in geographic education that had taken place in America during the past 25 years, data concerning collegiate geography were secured from 369 higher educational institutions. For this purpose a year's work was defined as geographic instruction extending through four or five hours weekly, for a school year. This was considered a better measure of growth than the increase in the *number* of courses and also of greater significance.

Twenty-five years ago the institutions reporting offered a total of 31 years of collegiate geography, including all duplications of the same or similar courses. Today 338.37 years, or an increase of 991.5 per

cent, are offered. The work in universities and colleges has grown from 11.25 years to 177.56 years, an increase of 1478.4 per cent, and in normal schools (now generally known as teachers colleges) from 19.95 years to 159.58 years, or an increase of 699.9 per cent. The relative decline in normal schools is of vital significance to those interested in elementary and secondary school geography teaching.

Wisconsin leads among the states with an offering of 34.95 years; Illinois is a close second with 34.83 years; New York is third with 33.1 years, and Ohio is fourth with 32.3. Further data from these states would probably change their rank, but they would remain at the head of the list, as Massachusetts, Pennsylvania, and Michigan rank next in order with about one-half the offering.

The leading institutions are the University of Chicago, Columbia University, and the University of Wisconsin. At least 15 years of consecutive work may be taken in the first-named institution. Eight other universities and six normal schools offer four to six and one-half years of collegiate geography.

Data recently collected by a committee of the National Council of Geography Teachers indicate that graduates of normal schools are yet very inadequately prepared to teach geography in the elementary and secondary schools. As these schools prepare most of such teachers this deficiency should be removed at the earliest date possible.

These data, from 75 normal schools distributed through 32 states, show that out of 5497 recent graduates 15.7 per cent had no geography in the normal school; 29.4 per cent had one 12-week course; 24.9 per cent had one 18-week course; 17.7 per cent had 24 weeks. 6.8 per cent had 36 weeks, and only 5.4 per cent had more than one year of geography. This is of vital significance owing to the fact that only a small percentage of these students have had any geography since they left the seventh grade, while nearly all of them will go out to teach the subject. If these same teachers had received no more training in history, mathematics, or English, these subjects would be as poorly taught and school administrators would demand immediate reform.

A. E. Parkins.

Topographic Types about Nashville (Illustrated)—Read by Title.

A study in response to types of topography in the Nashville region. About Nashville there are three strongly contrasted types of topography, the basin, the ridge and valley, and the highland.

G. T. Rude (Introduced by William Bowie).

Shore Changes at Cape Hatteras—Printed in full herewith.

C. S. Scofield.

Limitations of Irrigated Agriculture.

H. L. Shantz.

Urundi.

Urundi lies north and east of Lake Tanganyika. It was previously a part of German East Africa, but is now under a mandate exercised by the Belgian King. The country consists of an upland with rounded mountains, ridges and valleys. It is a rich grassland, excellent grazing country, supporting many cattle and a dense population of agriculturists. The dominant tribe is Hamitic, and almost entirely free from the influence of European civilization. The principal exports are palm oil, butter, beans, and hides.

J. Russell Smith.

The Division of North America into Economic Regions.

A Lantern Slide Map of North America was presented, showing a proposed division into regions.

H. N. Whitford.

The Climatic and Economic Relations of the Forests of Torrid and Temperate Zones.

Brief discussion of three classes of climate. Climatic conditions of three great forest regions; viz., Amazonian Evergreen Hardwood Forests, Pacific Northwest Coniferous Forests, and Deciduous Forests of Eastern United States. Comparison of these forests from climatic standpoint. Brief discussion of past climates in their relation to these classes of forests. The power of each class of climate to store up energy in the form of wood. This is expressed by the ratio of 1:2:4, that is, one stands for deciduous forests of temperate regions; two for coniferous forests of Pacific Northwest; and four, for the Amazonian forests. Significance of this relation for growing crops of timber. Present and future relations of the three classes of forests to furnish materials for economic use.

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